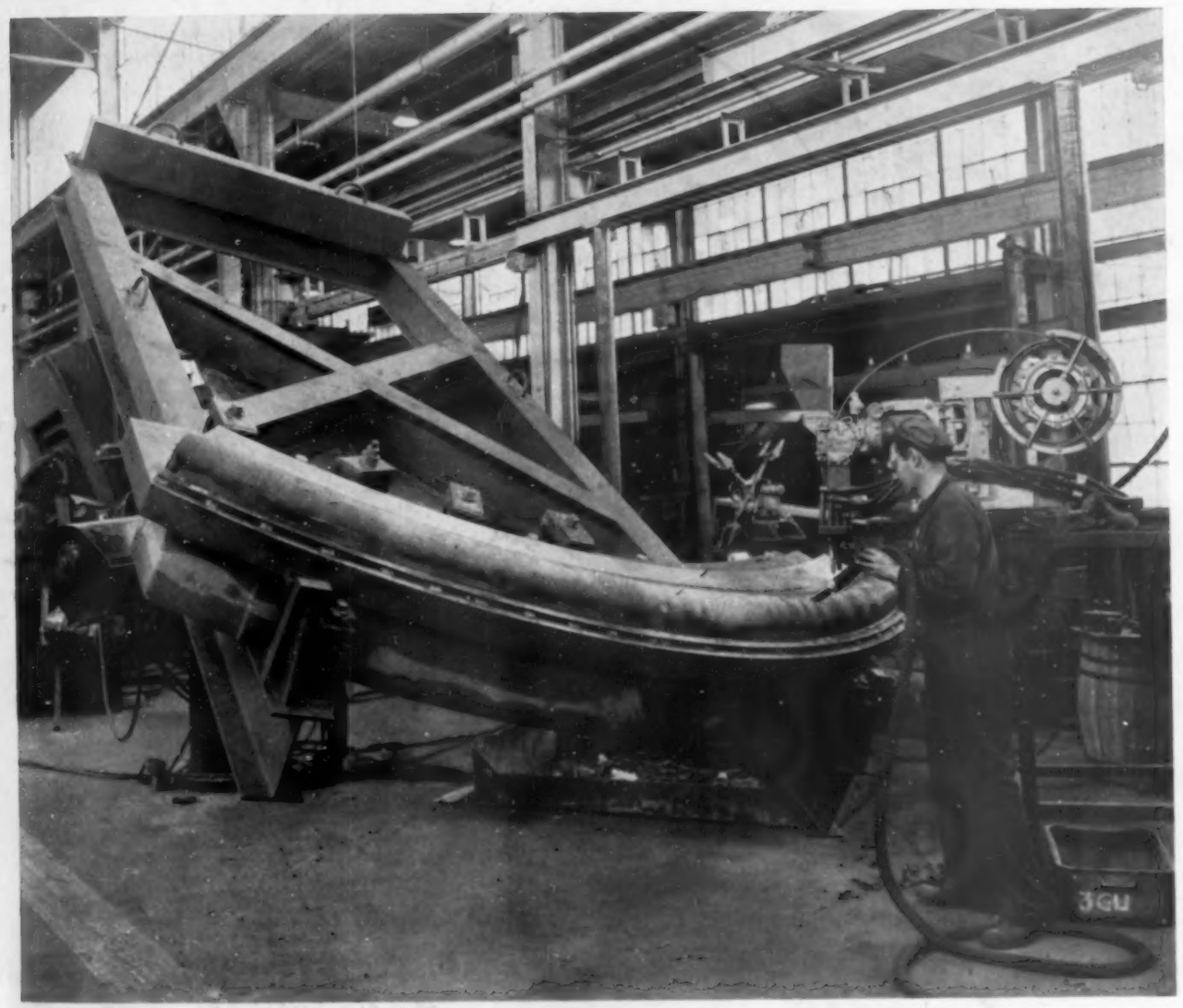
NOVEMBER 1946

The WELDING Journal



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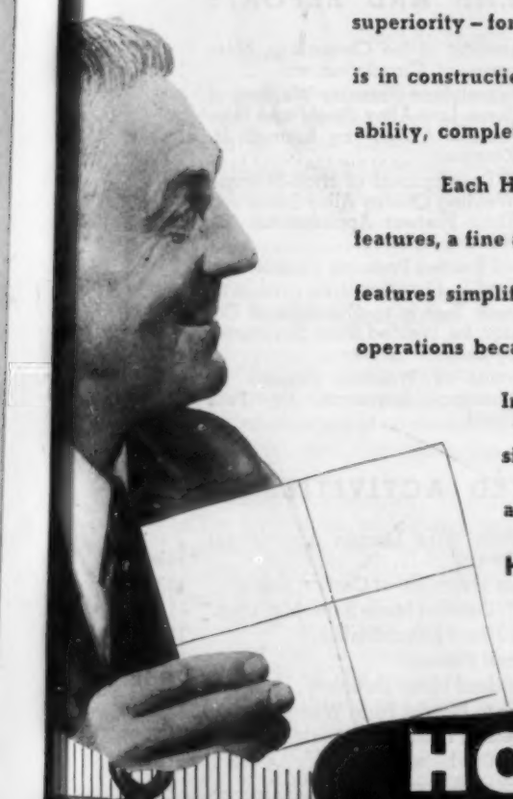

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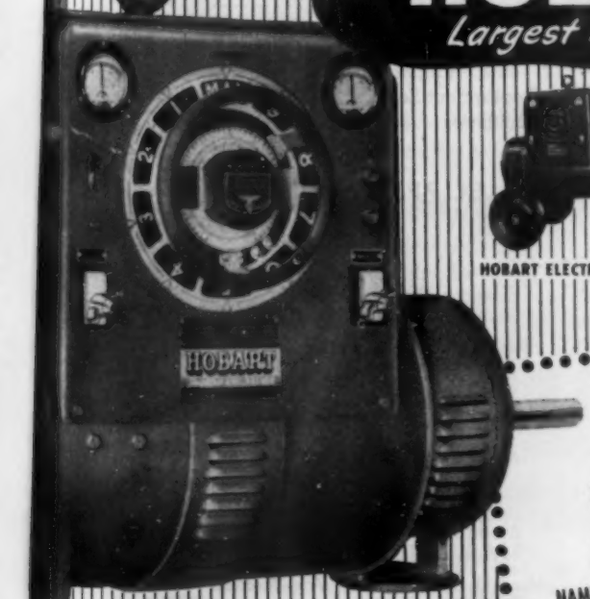

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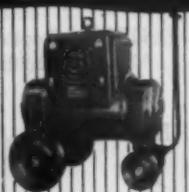

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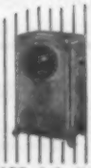

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Automatic Submerged Arc Welding of a Curved Tubular Section. *Courtesy Northern Ordnance, Inc.*

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Welded Freight Car Construction*

By R. L. Rex†

Introduction

IT HAS been my privilege, in recent months, to make a survey of the shops of leading railroads and car builders for the purpose of ascertaining current trends in welded freight car construction and it is desired in this paper to report, briefly, the more important results of that survey.

Railroad Welding in the Recent Emergency and in Current Reconstruction Programs

The contribution of the railroads in literally carrying America through the national emergency in the face of unprecedented shortages of materials and men is a matter of historical fact and, therefore, need not be elaborated upon.

Not commonly known, or, at least, appreciated, however, is the extent to which welding, flame cutting and allied processes were used in expanding railroad facilities and in keeping them in operation.

Not only was there a substantial increase in the extent to which these processes were used but also in the variety of new uses to which they were applied.

One indication of the expanded use of these processes may be found in Bureau of Labor Statistics data covering the period March 1940 through December 1943 showing a net increase of 625% in the number of railway employees performing welding and flame cutting operations compared with only 300% for industry as a whole and exceeded only by the phenomenal 2000% increase in shipbuilding.

In expanding their use of these processes, some railroads have gone far in exploring their respective possibilities and in setting up standards of design, operator qualification procedure, inspection and testing, with the intention of incorporating the best features of the practices recommended by the AMERICAN WELDING SOCIETY, the Association of American Railroads and other authoritative groups both outside and within the railroad field. While this tendency is, as yet, by no means universal, it is, nevertheless, growing and that, in itself, is highly significant.

In the reconstruction program, which has already been started, the possibilities of utilizing welding and allied processes in the fabrication of new freight cars and other sorely needed replacement items are being given extensive and thoughtful consideration.

In this connection, it may be noted that more than 30% of existing freight cars are over 25 years old and, taking this figure into account and relating it to normal replacement schedules, expected service demands and other factors, it has been variously estimated that approximately 1,000,000 new freight cars, including both home-built and purchased, will be acquired during the next 10 years.

Although it would be highly interesting to know how many of the new cars will be of all-welded construction, the meager information now available would preclude making an estimate.

Some indication of the trend, however, may be derived from the fact that one railroad recently accepted delivery of 500 all-welded freight cars, while another is building approximately 1000 in its own shops, and the fact that major car builders are featuring such cars in their current advertising. Also worth noting is the frequency with which relative ease of welding is claimed as an outstanding property of the numerous steels currently advertised in railway periodicals.

* Scheduled for Twenty-Seventh Annual Meeting, A.W.S., Atlantic City, N. J., week of Nov. 17, 1946.
† Railroad Mechanical Specialist, Air Reduction, New York.

Fig. 1—General View of Milwaukee Road Freight Car Shop Showing Production Line for Car Building

Fig. 2—Center Sill Positioner for Welding

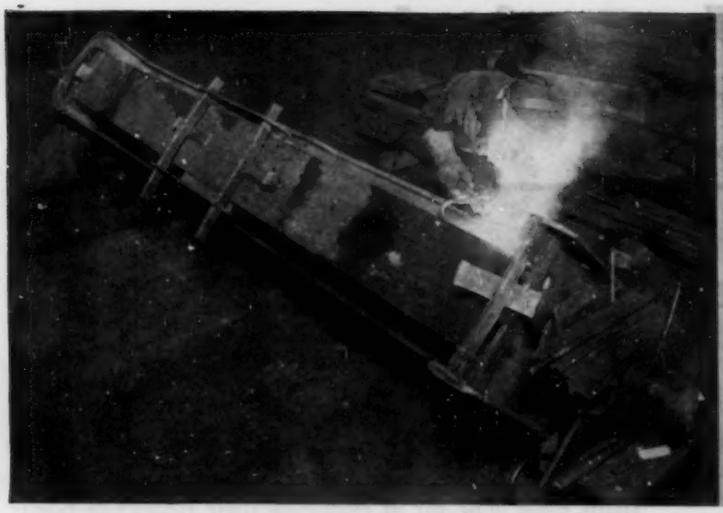


Fig. 3—Cross-Bearers, Right and Left, on Positioner for Welding

Fig. 4—Drop-Door on Welding Positioner

Weight-Reduction Possibilities Using Low-Alloy High-Strength Steels and Welded Design

The trend toward light-weight car construction which began some years before the war has been considerably accentuated because of new demands for speed and capacity. Although aluminum alloys and stainless steels have been used to some extent in building light-weight freight cars, the group of alloys commonly referred to as low-alloy high-strength steels have thus far enjoyed the most extensive use.

Upon examining the list of low-alloy high-strength steels, it becomes apparent that scarcely any two of them are exactly alike either in their chemical compositions or in their mechanical properties. In some, the carbon content is less than 15 points and in others it runs as high as 40. However a typical member of the lower carbon group which is understood to have been used in the construction of more than 60,000 freight cars, including both all-welded and riveted designs, is listed as having a carbon content not over 12 points, a yield point of approximately 50,000 psi., atmospheric corrosion resistance 4 to 6 times that of mild steel, and abrasion resistance about $1^1/_3$ times that of mild steel.

The extra strength of these steels, as compared to plain-carbon steels of equivalent carbon content, permits obtaining either less weight at the same strength, more strength at the same weight or a compromise effect of somewhat less weight and more strength. Thus far, the emphasis has been in the direction of obtaining less weight at the same strength. The use of all-welded construction also enters into these considerations owing to its elimination of the weight of rivets and their attending lap joints and its adaptability to more simple and correspondingly less weight-consuming design.

The over-all weight reduction resulting from the combined use of such steels and all-welded construction may, depending upon the type of car, range between five to seven tons. This reduction can be translated into one or more of at least three important advantages: (1) greater car capacity without increasing total load to be hauled; (2) less cars needed for a given amount of freight; or (3) less fuel expended in hauling a given length of train. In any combination, such advantages mean greater operating revenue.

Filler Metals Used in Welding Low-Alloy High-Strength Steels

In welding these steels, as in welding other alloy materials, proper selection of filler metal is a matter of paramount importance. In general, when plain-carbon filler metal is applied to a steel containing alloying elements, a

Fig. 5—Side Frame Assembly Jig

Fig. 6—Drop Ends on Jig

Fig. 7—Truckload of Bolsters (Outside), and Cross-Bearers (Inside)

Fig. 8—Bolster and Cross Sills Placed; Placing Center Sill

certain flowing or migration of these elements from the base metal into the deposited metal occurs as the two are melted and mixed together under the heat of fusion and this migration tends to produce in the deposited metal properties differing considerably from those which would be obtained if the same filler metal were applied to a plain-carbon steel. Owing to a difference in ratio of deposited metal to total melted metal when different thicknesses of section are welded, the rate of alloying element migration, in general, approaches the maximum in single-bead thin-section welds and approaches the minimum in multiple-bead heavy-section welds. Except in cases where the base metal contains excessive amounts of certain harmful elements, such as phosphorus, the results of this migration are, for the most part, beneficial. However, certain other exceptions apply depending on the welding conditions and the process used; therefore, it is wise to check the recommendations of the steel producer and the manufacturer of the filler metal before applying this principle.

Car builders are taking advantage of this principle by using plain-carbon filler metal wherever the migration effect is known to produce the desired properties and by resorting to the more expensive special or alloy filler metals only in the relatively few cases where higher strength or other special properties not obtainable with the plain-carbon filler metal are desired.

Distortion Control

The subject of distortion control warrants careful consideration in welding the low-alloy high-strength steels owing to the relatively thin sections generally encountered when such steels are used. This is particularly so in welding car roof and side sheets because any distortion in such members is distinctly more noticeable in welded construction than in riveted construction where uniform rows of rivets tend to draw the eye to themselves and to the smaller intervening areas, thus camouflaging the overall uneven contour.

Even if considerations of eye appeal are dismissed on the grounds that a freight car is essentially a utility and not a work of art, the fact remains that stresses inherent in distortion may cause cracks in service and this possibility cannot safely be disregarded.

Car builders realizing this have given distortion control the attention it deserves and, as a consequence, have developed a number of successful methods by which it or its effects can be minimized. Some of these methods involve changes in design, some involve changes in technique and some involve both.

Changes involving design include using lap joints in certain connections requiring special reinforcement not provided by the usual butt-welded joints; heavier or additional stiffening members; and crimped or corrugated sheets instead of plain flat sheets.

Changes involving technique include using wandering or skip weld sequence; additional or heavier weight cooling bars, clamps and positioners; and prestressing to introduce reverse camber.

Prestressing has, in general, proved to be the most practical and, for the most part, is performed when the parts are placed in the various jigs and positioners preparatory to initial assembly.

Fig. 9—Underframe Jig for Welding

Fig. 10—Picking Up Sill for Placing in Next Position

Fig. 11—Underframe in Welding Position on Trucks

Fig. 12—Placing Side Frames

Mass Production Methods Employed in Constructing All-Welded Cars

In order to illustrate the extent to which mass production methods are being applied to all-welded car construction, permission was obtained to photograph actual step-by-step assembly-line operations in a car fabricating shop of the Milwaukee Road (Fig. 1).

In setting up this shop careful thought has been given to layout and scheduling so that all things contributing to the finished product are caused to move steadily forward to the place of final assembly and to arrive there on time.

The shop layout provides two main assembly lines each connecting to a number of subassembly feeder lines.

Serving the two main lines are a group of five parallel standard gage tracks and an interconnecting system of strategically located supplementary tracks and switches.

As the car is being erected, it moves along from one specialized position to the next with time allowed for distribution of materials and men and eventually reaches one of the five parallel tracks where final erection, finishing and inspection operations are performed after which it rolls out to take its place among other cars in service.

The center sill (Fig. 2) is the main subassembly component of the underframe assembly and is what may be regarded as the backbone of the car. In fabricating this item, holes are cut into standard AAR Z26 Z-bar sections, using a hand cutting torch. The sections, held in a specially designed jig, are then welded together. Following this, the center filler, head blocks, draft gears, couplers, brake cylinders, brake rods and slack adjusters, are added.

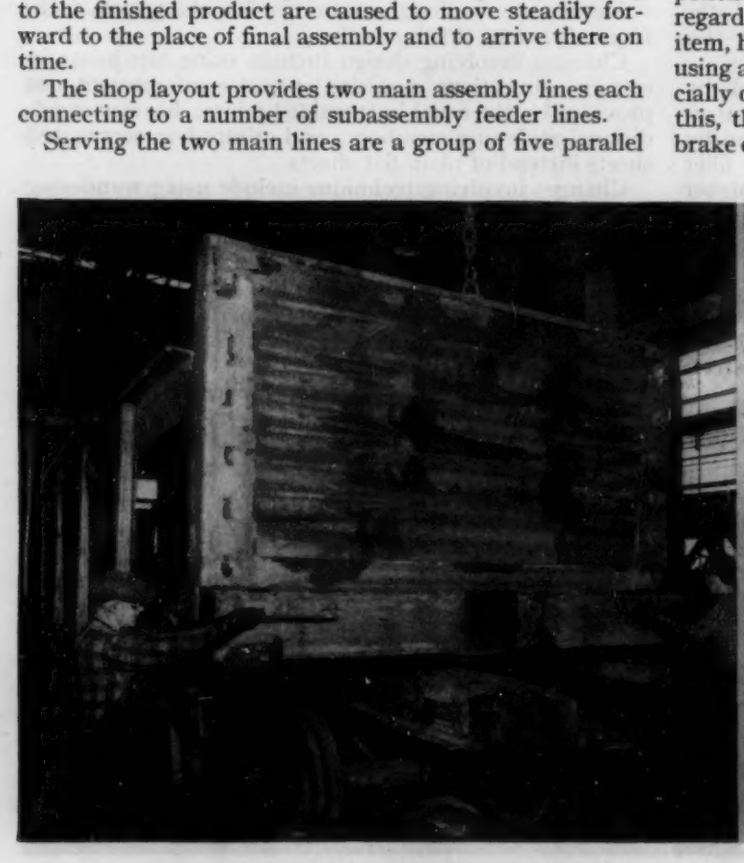


Fig. 13—Placing Gondola Car Body Ends

Fig. 14—Squaring Position; Long Range View of Side Frame Being Welded

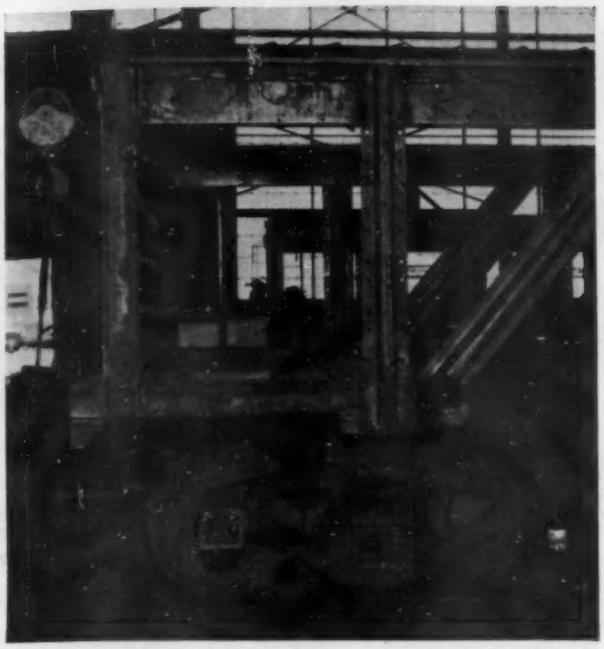


Fig. 15—Removing Blocks Between Bolster and Truck for Lowering Gondola Body on Trucks

At this assembly station, the center sill is welded only on its bottom side. The top side is welded later after the center sill has been combined with other components of the underframe asembly.

Also included among the subassembly components of the underframe assembly are the cross-bearers (Fig. 3). The plates used in fabricating these items are standard mill plates $^{3}/_{16}$ in. thick for sides and $^{7}/_{16}$ in. thick for top and bottom. During fabrication, the plates are held in proper position for welding in a revolving combination jig positioner which consists primarily of a trunnion-mounted horizontal shaft and correct alignment of the plates is assured through the use of simple saddle and wedge clamping devices. The use of jigs, fixtures and positioners and of combination jig positioners such as this is one of the outstanding developments contributing to the rapid advances being made in all-welded car construction.

Drop doors (Fig. 4), also subassembly components of the underframe assembly, are fabricated by welding in another type of positioner. Each drop door consists of a door base plate made of standard mill plate, stiffeners made of standard mill Z-iron and a T-shaped door lock catch. The T-shaped material out of which the catch is made consists of a split section of a standard mill I-beam which is either sheared at the mill or machine gas cut at the shop.

The side frames (Fig. 5), although practically major assemblies in themselves, are subassembly components of the car body or superstructure assembly. Each side frame consists of a side plate, a top reinforcing chord, a side sill and several posts and braces. The posts and braces are made of rectangular sections of standard mill plate which are either sheared to size at the mill or machine gas cut in the shop and then formed by hot punching in a hydraulic press. The top reinforcing chord is made of standard mill bulb angle. In the jig which holds these parts in alignment for welding, use is made of shop-made hold-down clamps.

Drop ends (Fig. 6), like the side frames, are subassembly components of the car body assembly. Each drop end consists of a drop-end gate, a reinforcing top angle, gussets and end sills. The drop-end gate is made of formed angle shapes. The other parts are machine gas cut to size and are bent to shape in a press. The jig is designed not only to permit flat position welding but also to minimize operator fatigue by holding the sections at table height.

Bolsters (Fig. 7), like the previously mentioned cross-bearers, are subassembly components of the underframe assembly and are made of standard mill products using a trunnion-mounted horizontal-shaft positioner. These and other subassemblies are fabricated in advance and are stacked at convenient points along the subassembly lines so as to be ready when the work of erecting the car begins.

Erection of the car begins when the various component subassemblies of the underframe assembly are set up for welding in the underframe jig (Fig. 8). After setting up such items as the bolsters, cross-bearers, cross-ties, drop doors and *AB* brake valve, the center sill, shown hanging over the jig, is brought in. The center sill and all other heavy items are transported by means of overhead traveling cranes.

The center sill (Fig. 9), upon being lowered into the

Fig. 16—Milwaukee Gondola Car

jig, is brought into accurate alignment with other underframe components, and the welding proceeds. In this connection, it should be noted that up to now the center sill and other underframe components have been positioned bottom side up. This has been done so as to allow, in so far as possible, the use of the flat position of welding in fabricating the bottom side of the underframe and also to permit all bottom side welding to be done before turning the assembly over for top side welding.

When all bottom side welding is completed, one of the cranes (Fig. 10) is again brought into action. Using a pair of roll-over slings, the entire underframe assembly is lifted out of the jig and turned top side up after which it is swung over one of the interconnecting tracks.

On this track (Fig. 11) are the trucks ready to meet the underframe. These items were brought to this location after being previously assembled elsewhere. As the underframe is lowered onto the trucks, wood blocks are inserted between the truck frames and the bolsters so as to provide space for final welding of main assemblies. Then, as soon as the underframe is in position, its top side welding is completed, the air brake piping is added, and this completes the first major step in erection.

The side frames (Fig. 12) are then brought in by means of a crane and are swung into position on the underframe. As at other assembly stations, specially designed jigs are used to hold the side frames in correct alignment for welding.

The drop ends (Fig. 13) are then brought in by means of a crane and, after being correctly aligned with the underframe and side frames, are welded in place. Other items added at this station include the hand brake bracket, floor stringer supports, pin lifter bracket, end plate and end plate hinges.

The nearly completed car (Fig. 14) then moves to the next assembly station where final welding of the main assemblies is completed.

After the final welding is completed, the wood blocks which were previously inserted between the trucks and bolsters are removed (Fig. 15). The car then moves to the next assembly station where the wood flooring and siding and the various safety appliances are added following which the car is painted and given final inspection.

Fig. 17—Milwaukee Automobile Car

The completed car (Fig. 16), which is of the gondola type, then rolls out of the shop and is ready to take its place in service.

Another example of the cars being built at this shop is the all-welded automobile car (Fig. 17). The work of erecting this car proceeds somewhat differently than in connection with the car previously shown but, in general, the principles involved are the same.

Thirty years ago, freight car parts were joined largely by means of bolts and nuts. Along came rivets, and initially their use met with opposition but they, nevertheless, continued to be used. Then came welding and it, too, met with similar opposition but it also continued to be used and its use is being everywhere extended. Rivets continued in use only because they served the purpose better. Welding will do likewise.

WELDED BUILDING

W. S. Bellows Construction Co. is the general contractor on the 25-story City National Bank Building in Houston, Texas, that was designed by A. C. Finn, Architect, and Robt. J. Cummins, Engineer. This structure will involve some 3800 tons of structural steel, and was designed for welding in shop fabrication and field erection. Construction has been under way for the past several months and steel work should be completed by the end of the year.

Mosher Steel Co. is fabricating structural steel members, and Peterson Brothers are the contractors on the field erection and welding. Between 20 and 27 welding operators have been employed on the field work most of the time, and shop and field welding is being done in accordance with the AMERICAN WELDING SOCIETY "Code for Arc and Gas Welding in Building Construction."

Supervision of fabrication, erection and welding is being handled by Southwestern Laboratories.

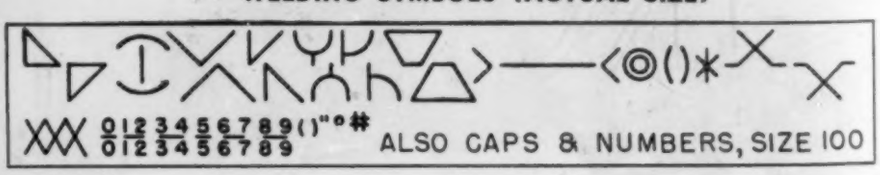
LEROY WELDING SYMBOL TEMPLATE

Keuffel & Esser Co. have added an item to their Leroy equipment for lettering and symbols, which is a great time-saver in drawing accurate welding symbols. This is the Leroy Welding Symbol Template.

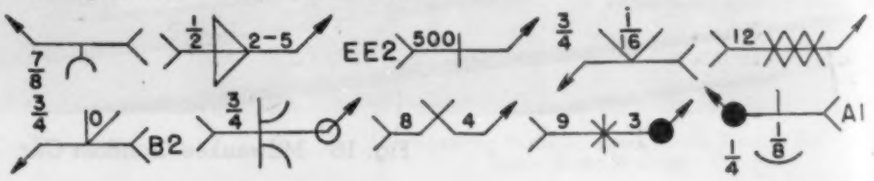
The new Leroy Welding Symbol Template forms symbols covering arc, gas and resistance welding, also fractions in the size shown in the illustration. In addition it forms capital letters and numerals of the size shown (0.10 in. height). All the welding symbol components adopted by the AMERICAN WELDING SOCIETY and approved by the American Standards Association are included on the template. These components can be combined to form all required welding symbols.

For further information on Leroy lettering and symbol equipment write Keuffel & Esser Co., Hoboken, N. J.

WELDING SYMBOLS (ACTUAL SIZE)



Examples of combinations that can be made:



Resistance Welding with Storage-Battery Power*

By John D. Gordon†

RESISTANCE welding has been recognized by the metal working industry for some time as the simplest and fastest method of joining parts. Its use has been widely adopted for the mass production of identical assemblies in practically every industry employing steel fabrication. Recently the increased demand for high-production welding equipment led to the development of storage-battery powered resistance welders to overcome the inherent limitations of conventional welding processes especially when applied to aluminum and its alloys.

A simple spot weld is made by passing a heavy electrical current through metal parts while they are held in intimate contact. The heat for the formation of the weld nugget is generated by the resistance of the metal to the flow of electrical current; being directly proportional to the square of the current, the electrical resistance of the metal and the time current is applied. The intesnity of the current must be sufficient to fuse the nugget before the heat is conducted away by the surrounding metal. Since aluminum is a good conductor of both electricity and heat it is relatively difficult to spot weld compared to steels. It requires very high welding currents of relatively short duration.

It is possible to weld aluminum and its alloys with conventional a.-c. resistance welders, modified to deliver welding currents in the range of 10,000 to 30,000 amp. However, the power line demands of such machines are excessively high and they operate at a very low power factor. A typical a.-c. aluminum welder has a demand of about 400 kva. at 40% power factor, lagging. It is infrequent that power supply is available for equipment in this power demand range. Since most power rates are based on a dominant demand charge with a penalty for low power factor, the operation of such machines is costly and the investment in plant necessary to provide heavy duty power lines from the machine to the source of supply is often prohibitive. In many industrial localities the power facilities are not capable of doing the job at all.

"Stored energy" types of welding machine offered the solution. Energy could be supplied to machines at a low rate, stored and then delivered at a high rate for welding. Two types of "stored energy" machines had been developed. One type makes use of direct current to build up an intense magnetic field in a specially designed transformer. When the current is interrupted the rapid collapse of the magnetic field momentarily induces a high current value in the welding circuit to produce a weld. The other machine type converts line power to a high d.-c. potential to charge a bank of condensers. The discharge of these condensers through a transformer into the welding circuit produces the weld.

Both machine types are an improvement over the conventional a.-c. welders in that they can be operated on 3-phase supply with consequent reduction in power line loads. Their power demand averages about one-fifth that of the a.-c. welder. The control of the duration of the welding current is limited, and the initial cost of this equipment is high compared with conventional a.-c. machines. The storage of energy is a part of the machine's operating cycle; actual spot welding rates usually do not exceed 80 spots per minute.

Fig. 1—Typical Storage-Battery Powered Resistance Welder Installation. Approximately 29,000 1/8-In. Steel Spot Welds Are Produced Each 20-Hr. Day. Power Demand Is Only 26.7 Kva. Balanced on Three Phases. Power Factor Is 85%

The most obvious method of storing electrical energy, of course, is the storage battery. Energy can be supplied to it continuously at a low rate, stored for an indefinite period and used as required. Battery chargers are widely available in package units. These have a high efficiency, draw a high power factor type of load and are simple to operate. However, the problem of interrupting the enormous low-voltage direct currents that are required in resistance welding at one time seemed insurmountable. However, a very common device—the carbon pile rheostat—has now solved this problem. The development of a form of this laboratory instrument adaptable to routine resistance welding has thus made welding with storage battery power a practical industrial tool. As a result, incidentally, resistance welding has been freed from high-capacity power lines, permitting metal working plants to be located in small towns and outlying districts, away from major industrial areas.

Storage-battery powered welders are similar in design to conventional a.-c. resistance welding macines. The essential difference is that a bank of storage battery cells replaces the customary welding transformer. The mechanical operation of battery type spot, projection, roll-spot and flash welders—stationary or portable—is

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† General Manager, Progressive Welder Co., Detroit.

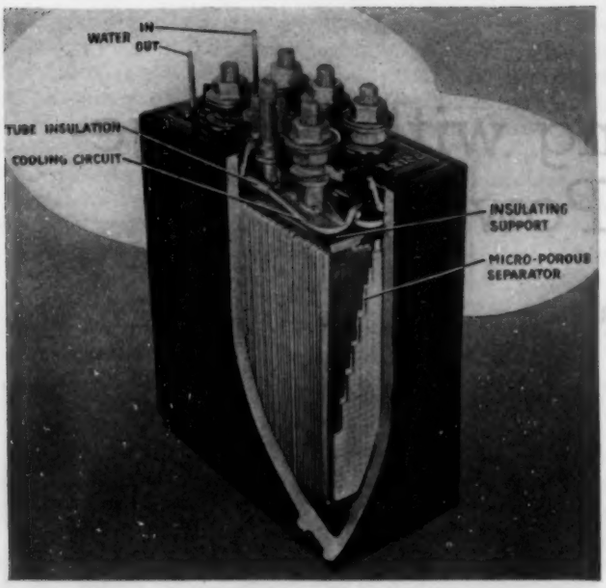

Fig. 2—Cutaway Section of a Water-Cooled Storage Cell Developed by Progressive Welder Co. Note the Six Heavy Terminals for Conducting Welding Currents Up to 7000 Amp. per Cell

the same as for conventional a.-c. type machines. Control equipment for battery welders such as timers, "heat" regulators and contactors are simpler and easier to maintain than those for other types of stored-energy machines.

The flexibility of storage-battery welders seems to be unlimited. Their welding capacity can be extended merely by increasing the number of cells used and welding rates depend primarily on the output capacity of the battery charger employed. The range of materials that have been successfully spot and projection welded extends from very thin gage mild and stainless steel to heavy gage $^1/_4$-in. aluminum alloy sections. Battery-powered welders have made possible, for the first time, the economic use of stored energy equipment in both multi-spot and flash welding. The absence of an interval for charging between welds of a sequence, required by conventional stored energy machines, permits battery-powered multi-spot welders to equal and possibly even exceed, in some cases, the welding rates of a.-c. machines. The flash welding even of aluminum and other metals having a narrow plastic range—materials heretofore considered relatively unsuitable for flash welding—can now be performed on a production basis from ordinary factory power lines, without prohibitive power demands.

A typical battery-powered single spot welder installation is shown in Fig. 1. This rocker-arm type machine houses 12 storage cells. At left is the charger unit with an electronic timer mounted at the top. This welder makes 240 spot welds to assemble the part shown from "laminated" thicknesses of $^1/_8$-in. structural steel. Approximately six assemblies are completed per hour. Total output for two 10-hr. shifts is around 29,000 welds. Welds are closely spaced in rows permitting a weld to be made every $^1/_2$ sec. by automatic machine cycling. Operating 20 hr. out of every 24, this machine has a higher production than the 150-kva. conventional a.-c. welder it replaced. It supplies 20,000 amp. of welding current with a total power line demand of only 26.7 kva. —less than one-fifth that of the comparable a.-c. welder. In addition, the load is continuous and balanced on all three phases of the power supply at approximately 85% power factor while the a.-c. welder drew its entire load from one phase at approximately 40% power factor.

The Water-Cooled Battery

In welding service it is desirable to maintain as high a charging rate as possible in order to obtian the maximum output with the least number of batteries. The effective capacity of a storage battery is limited, however, by the temperature rise of the cells during charging and discharging. The use of a new type of battery, designed originally for maritime service, plus the addition of an internal water cooling circuit in the battery has increased the practical capacity several times over that of conventional batteries. In addition, the life of the battery is increased and maintenance reduced.

Cooling of the cells is accomplished by use of some 50 in. of $^1/_4$-in. O.D. lead tubing in the electrolyte near the top of the cells (Fig. 2). Tap water is circulated through the tubing at a rate determined by the requirements of the operation. The lead tubing is insulated from the plates by insulators of special hard rubber, and from contact with the terminals by enclosing the tubing in rubber sleeves at these points. Positioning of the cooling circuit near the upper surface of the electrolyte also materially reduces the excessive loss of electrolyte associated with uncooled batteries.

Precise control of battery voltage during charging greatly reduces the generating and escape of hydrogen even with the welder under heavy duty operation.

Micro porous separators retard the loss of active material by the plates. Deep sediment receptacles at the base prevent the normal accumulation of sulfide from shorting the plates. Each cell is provided with six heavy terminals in place of two to reduce the voltage drop of the cell to a minimum and to provide ample capacity for an average of 7000 amp. normally delivered by each cell during welding. Even at high-duty cycle service, the cells remain cool.

The cells are "banked" as required for the specific welding service. That is, two or more cells are connected in series to provide the proper welding voltage—usually 4 to 10 v.—and a sufficient number of cells are connected in parallel with these to supply the amount of

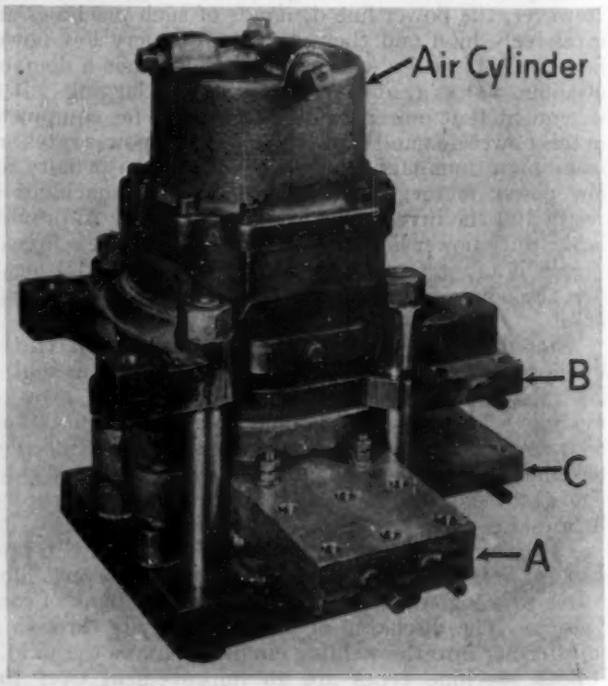

Fig. 3—The Heart of the Progressive Storage Battery Powered Welder Is the Air-Operated Contactor-Controller. The Unit Shown Is Capable of Interrupting Up to 40,000 Amp. Without Arcing

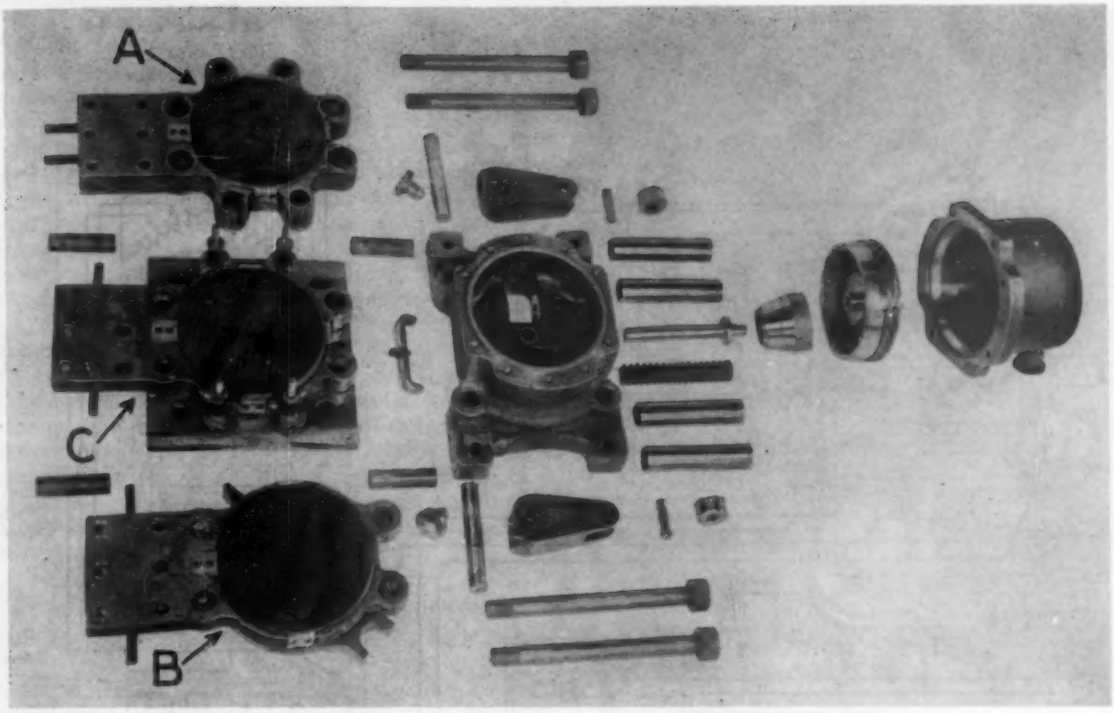

Fig. 4—Disassembled View of a Contactor-Controller After 1,000,000 Welds. Note the Original Tool Marks on the Carbon-Graphite Contact Surfaces Indicating the Absence of Erosion

welding current needed. Banks of 6, 8, 12 and 16 cells are common. The size of the battery selected for a particular welding operation usually results in a reserve capacity sufficient to make approximately 2000 welds in the event of power supply failure.

The Contactor-Controller

The construction of a typical heavy-duty contactor-controller capable of making and breaking welding currents up to 40,000 amp. continuously at 200 times per minute is shown in Fig. 3. Three circular copper alloy plates, with connection terminals, support four carbon-graphite contact disks.

Mounted below an air cylinder, the upper plate is connected to the piston through a cam linkage. The disassembled view (Fig. 4) shows the two carbon disk contact surfaces of the central plate and the single contact surface of the upper and lower plates. When those parts are assembled with springs and guides, the contact surfaces are just barely separated (0.090 in. maximum). When the contactor is operated the carbon disks are forced together under a pressure of approximately 1000 psi.—amounting to 50 tons' pressure on one size unit.

It will be noted that the four contacting surfaces offer two paths for the flow of welding current: from the central plate to both top and bottom plates. This cuts the voltage drop in the contactor to half compared with using only two plates.

When pressure is first applied to the plates the resistance to the flow of current is extremely high. As applied pressure increases, the resistance of the carbon disks to the flow of current decreases rapidly until under full pressure there is practically no resistance and full welding current flows through the contactor.

To stop the current flow, air pressure is removed, allowing springs in the assembly to separate the plates. Upon release of the contacting pressure the resistance of the plates increases rapidly with the decrease of pressure so that, at the instant the plates separate, there is practically no remaining current to be interrupted. Proper selection of the carbon-graphite material and the thickness of the disks provides the desired pressure-resistance characteristics.

No arcing occurs at the contacts. The only visible indication of current interruption is the presence of occasional minute incandescent particles of carbon dust that glow momentarily between the separating contact sur-

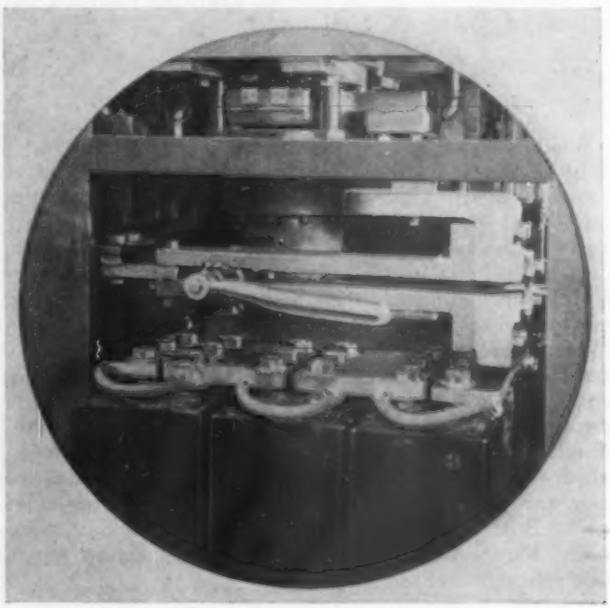

Fig. 5—Wide Range Stepless Welding Current Regulation Is Provided by the Simple Cast-Iron Rheostat of the Battery Welder. Adjustable Arm Indexes on a Graduated Scale for Calibration and Reference

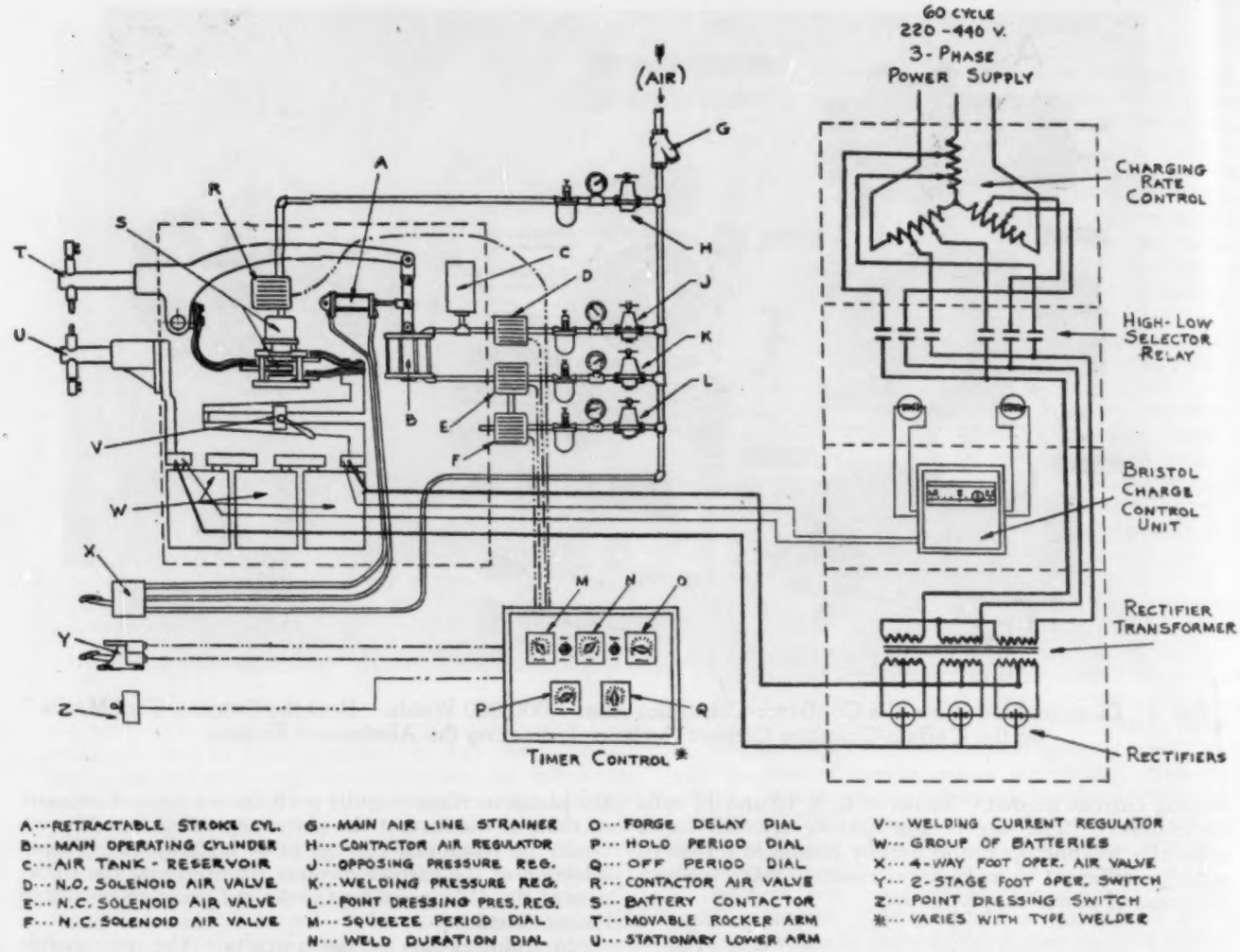

Fig. 6—Schematic Diagram of a Typical Storage-Battery Powered Welding Machine and Charger

faces. Water-cooling circuits within the copper mounting plates carry away the heat generated permitting continuous re-cycling all day long.

Welding Current Regulator

Welding current can be controlled by the arrangement of battery connections in steps of approximately 2 v., but this method does not provide the precision required by most welding operations. This is particularly true for the welding of thin sections of steel or of aluminum and other materials having a narrow plastic range. Wide range, stepless adjustment of welding current is provided by means of a lead-covered cast-iron rheostat interposed in the welding circuit (Fig. 5). Movement of the sliding contact block along the U-shaped member introduces more or less resistance into the circuit as required. Adjustment range is usually from 50 to 100% of maximum current. A quarter turn of the adjustment arm locks the contact block in place and also indexes it on a graduated scale for calibration or re-setting reference. Both resistor element and contact block are water cooled to maintain constant current regulation over a wide range of welding rates.

Welder Control System

The mechanical operation of storage-battery powered welders is similar to that of conventional a.-c. welders. Figure 6 shows a schematic layout of a typical rocker arm type of machine. Adjustable electrode pressures, provided for Squeeze, Weld, Forge and Hold intervals, are supplied by a pneumatic system. Two solenoid-operated valves admit air to either end of the rocker arm

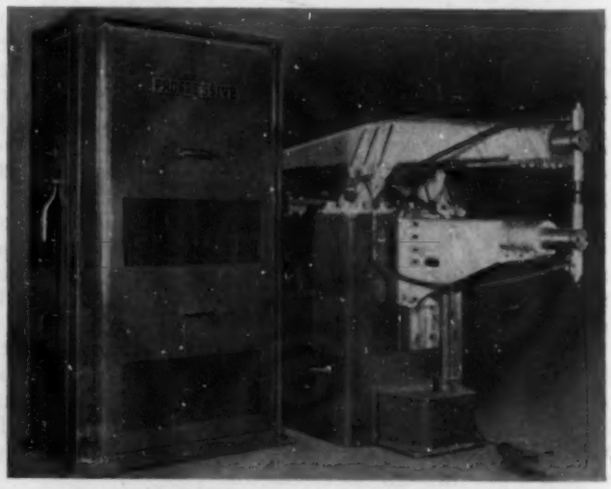

Fig. 7—The Power Supply of This Storage-Battery Welder Is Housed in a Separate "Power Pack." Such Units Can Be Readily Connected to a Wide Range of Machines to Provide Increased Welder Flexibility

air cylinder. The upper valve (normally open) separates the electrodes. The lower valve (normally closed) provides squeeze, weld, hold and differential pressures when open. Closing the upper valve while the lower valve is open provides forge pressure, exhausting the upper cylinder. The timing and sequencing of the valve movement is by a simple electronic timer and two-stage foot-operated initiating switch. Additional controls include movable arm retraction by means of an air cylinder and toggle linkage in the connecting rod, and a light electrode pressure for point dressing. This is supplied by a low air pressure acting on the main cylinder piston when the upper air chambers are exhausted. The contactor is also operated by an air valve controlled by the timer.

A simple differential-cam type timer is often used in place of the electric timer shown. The cams are mounted on a common shaft for direct operation of the air valves. A single revolution clutch, controlled by the initiating switch, engages an adjustable speed drive to rotate the cam shaft each welding cycle. Interest has been shown in this timer because its operation is more easily understood than that of an electronic device.

Battery Charging Control

Three-phase full-wave dry disk type rectifiers and specially designed controls are employed to convert the usual factory a.-c. power to d.-c. and maintain the storage cells at the proper charge. The charger and controls can be assembled as a separate unit or one or

Fig. 9—Typical Storage-Battery Powered Aluminum Flash Welder Assembly Welding the Miter Joints of Extruded Section Aluminum Window Sash. The Low Power Demand and Non-critical Controls of the Battery Flash Welder Make Structural Section Aluminum Fabrication Practical for High Production

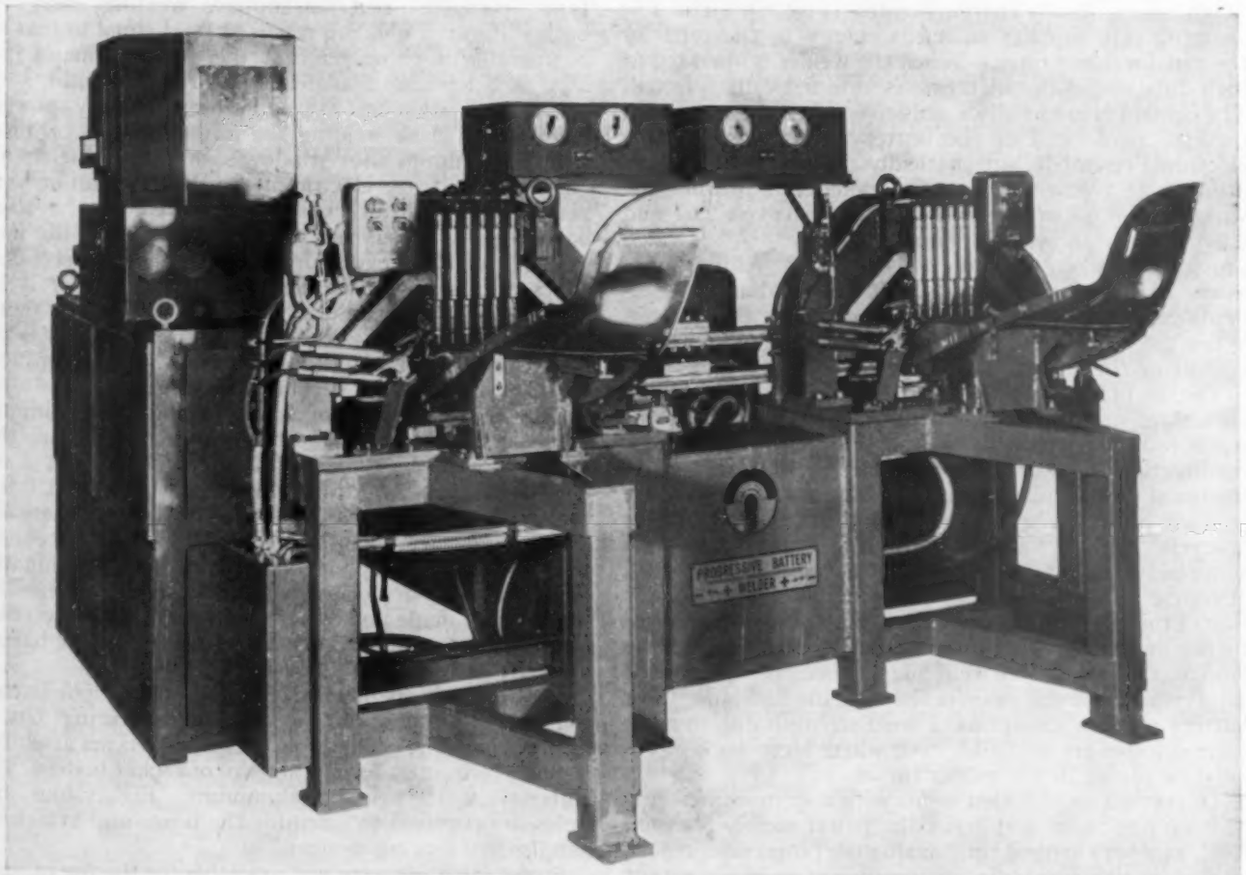

Fig. 8—A Two-Station Storage-Battery Powered Multiple Spot Welder Designed for the Assembly of Automotive Fender Panels. Battery Power Permits High Production of Such Complex Assemblies at a Low Power Demand

Fig. 10—A Group of Battery Welders Spot Assembly-Welding 0.081 to 0.081 In. 3S Aluminum Rocket Body Containers at Aluminum Goods Manufacturing Co., Manitowoc, Wis.

more components can be housed within the welder (Fig. 7). This type of charger is fully automatic and requires very little attention except when changing welding operations.

A tapped auto-transformer and two selector switches provide a wide range of current adjustments for both "high" and "low" charging rates (Fig. 6). The low charging rate supplies sufficient energy to the cells for the usual welding rates. When the welder is operated at high-duty cycles the high rate is automatically selected. The control is essentially a sensitive voltmeter connected to one "pilot" cell of the battery operating a simple electronic circuit to automatically maintain the battery at a preset voltage. The usual practice is to limit the variation of potential of the cells to between 2.07 and 2.2 v. This allows a tolerance of only $3^1/_4\%$, which provides satisfactory regulations for most welding processes. Although highly sensitive, heavy damping prevents demands of a single weld from starting the charger. When the welder is idle, the charger operates periodically, equalizing the charge among the cells.

The use of storage battery power for resistance welding eliminates many of the causes of poor and inconsistent welds resulting from a.-c. welding current. Continuous unidirectional power is supplied to the weld instead of the usual power pulses which rise from zero to maximum in each direction and reverse 60 times per second for 60-cycle service. Such alternating current induces some eddy currents in the mass of the work piece. This, of course, is a loss and does not contribute to the formation of the weld. The amount of this loss is proportional to the mass of the work piece enclosed by the welding loop, so that successive weld nuggets become smaller and smaller as the work piece is fed into the machine. For battery welders variations of weld strength due to eddy current losses are negligible even where large work pieces must be placed in the welder throat.

To prevent inconsistent welds with a.-c. machines, it is necessary to make and break the power supply for each weld, at a very critical time during the power alterations. Otherwise either excessive or insufficient welding current may be drawn and "too hot" or "too cold" welds result. This is usually accomplished on a.-c. machines by the use of complex electronic controls that are quite costly to install and maintain. This problem does not arise with battery welders because an unvarying welding voltage is available at all times.

Battery power provides a large reserve of power capacity that is not affected by fluctuations of power-line voltage due to the operation of other electrical equipment on the same circuits. It is often necessary to interlock the controls of a group of a.-c. welders to prevent simultaneous operation and the resultant interference with the production of identical welds. This is unnecessary when battery welders are used.

It is often desirable to house the batteries current regulator and contactor-controller in a separate "package" unit to provide additional flexibility for battery-powered welding equipment. The "power pack" shown in Fig. 7 can be connected to any type of battery welder and other power packs can be connected to the same machine to increase its welding capacity in steps of approximately 25,000 amp. of welding current. Thus welding equipment need no longer be confined to a narrow range of utility. The interchange of machine and power packs can provide almost unlimited conversions in the event of product re-design or major engineering change.

An application of battery power to high production multi-spot welders is shown in Fig. 8. This two-station machine spot welds 11 points to subassemble and automotive fender panel at each station. The two stations are interlocked permitting one station to weld while the other is being loaded. The welds at each station are made in two groups. In the first group five welds are made simultaneously. In the second group, six welds are made simultaneously. The second set of welds follow the first automatically in rapid sequence. A single 8 v., 16-cell power-pack charged by a 3-phase dry disk type "package" rectifier supplies welding energy for both stations. Welding rate is at least equal to that of a comparable a.-c. welder and the power demand is at least 80% lower and balanced on three phases.

Figure 9 shows a typical storage-battery powered flash welder flash welding the mitered joints of an extruded aluminum alloy window sash. The machine is a R.W.M.A. Size 3, electric-motor driven, cam-operated platen type with air clamping. Powered by a 16-cell battery pack, it supplies 35,000 amp. during the upset period. Welding cycle for this section is $^{35}/_{60}$ sec. flash, $^{5}/_{60}$ sec. upset. Power demand of the charger is less than 20 kva. balanced on 3 phases at 85% power factor. A comparable a.-c. flash welder would impose a 300-kva. single-phase demand at approximately 50% power factor on the power lines for such an operation.

The timing control for flash welding of aluminum is much less critical with battery-powered machines than with a.-c. welders. The duration of upset current of a.-c. c. welders is usually critical to within $\pm^1/_{60}$ second. Battery welders apparently are not critical under these conditions and variations of from $^1/_{20}$ to $^1/_6$ of a second is permissible in the upset current time. The elimination of the necessity for complex synchronous electronic timing controls made possible by this inherent characteristic is a not unimportant additional advantage of the battery powered flash welding process.

Figure 10 shows another group of single-spot battery welders at Aluminum Goods Manufacturing Co. in Manitowoc, Wis. This group of six welders are assembly-welding containers for the storage of rocket bodies. The material is 0.081 in. 3S aluminum. Eighty-four spot welds are required to assemble the boxes and attach the handles and locking devices.

Power facilities were not available for the use of other types of stored-energy welders. The company estimated that the cost of a condenser discharge type welder installation would have cost 40% more than the battery power welding equipment installed.

Additional Timing Period of New Motor-Driven Control Increases Gun Welder Speed*

By H. I. Stanback†

RESISTANCE spot welding at high production rates is playing an increasingly important part in many manufacturing industries concerned with sheet metal fabrication. A typical example would be the modern automobile body assembly line, where spot welding is used very extensively. Fabrication of an auto body requires a great number of separate operations, and labor represents a large portion of the cost. It is essential, therefore, that each operation shall take as little time as possible. Savings of split seconds on individual operations can easily add up to worth-while cost advantages on the complete product.

Equipment capable of producing welds at high speed has been available for some years. However, several difficulties have been encountered and some production jobs have actually had to be slowed down to avoid them. Two of the most serious problems at high welding speeds have been (1) to achieve welds of consistent strength and quality and (2) to keep from losing production due to excessive maintenance requirements.

All of the elements of the welding system have been subject to mechanical difficulties—electrical control devices, solenoid air valves, even the welding tools themselves. These difficulties have been the natural consequence of the rapid mechanical motions required and the severe duty cycle. However, considerable improvement has been made in recent years. Speeds which once would have quickly worn out equipment or caused frequent breakdowns can now be satisfactorily used for many types of jobs.

It should be noted that "high speed welding" cannot be defined in general terms. One hundred spots per minute might be a very high speed for a job involving a long stroke tool and work awkward to handle. On the other hand, 400 spots per minute has been found practical with certain short stroke guns making seam type joints with overlapping spot welds.

Control Requirements

The welding cycle for the average gun consists of four separate time intervals—*squeeze*, *weld*, *hold* and *off*. The control equipment must keep each of these four periods as short as possible without adversely affecting weld quality. Individual analysis will clearly indicate the possibility of time loss through inadequate control. To get the most out of any given welding gun and associated equipment, it is necessary to reduce each timing period in the control sequence to a minimum and avoid loss of time in transition from one period to another.

Many welding guns are set up with operating strokes of several inches. This much electrode travel is needed to clear projections or obstructions over which the tool must pass in getting to the proper welding position. The long stroke is clearly necessary on the first operation but often a much shorter stroke would be desirable for all the following welds in a repeat series. Once the tool has reached the welding position the electrodes need open only far enough to release the work and allow movement of the tool to the next spot position. Therefore, the control should somehow be able to provide for the long stroke on the first operation and a much shorter stroke on succeeding operations.

Squeeze time is defined as the time from application of electrode force on the work until the first application of current. However, the actual squeeze timer setting on the control must also include the delay required for closing the electrodes after electrical energization of the valve solenoid. Usually the total operating time of the valve and gun is longer than the actual squeeze time required for pressure build-up after the electrode touches the work.

It is obvious that the requirement described above for different stroke lengths will mean that the control must provide different squeeze timer settings to avoid wasting time. A conventional control would give a sufficiently long squeeze time on the first weld and use the same setting on all succeeding welds. A desirable timer, however, should greatly reduce the squeeze time setting on succeeding welds.

Weld time includes only the actual interval during which welding current flows through the work. Unless relatively expensive and bulky synchronous, precision control is used, short weld times have ordinarily resulted in poor quality work due to starting transients and timing inaccuracies. Conventional nonsynchronous controllers have, therefore, been limited to minimum weld times of approximately three cycles. Short weld times are obviously desirable for higher speed operation. In order to attain satisfactory weld quality at high speed, the control should have somewhat greater timing accuracy than the conventional nonsynchronous devices. The starting transient effect could also be more easily tolerated if the effect were consistent rather than random and if the effective heating value of the current could be made approximately the same for all welds. Therefore, consistency of the weld current starting point with regard to the line voltage wave would be an important design goal.

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† Square D Co., Industrial Controller Div., Milwaukee 12, Wis.

Hold time is defined as the time during which the electrodes are held under force at a fixed point on the work after current ceases to flow. This interval is necessary for two reasons: (1) to allow resolidification of the weld and (2) to permit the electrodes to conduct away surface heat where excessive marking of the work is objectionable. Normally the hold time can be very short. The time setting on the control will be shorter than the actual hold time required because the valve solenoid must be de-energized ahead of time to allow time for valve operation, exhaust of the air cylinder and opening of the electrodes. In some cases with large, slow acting tools, the time required for the valve to operate and for the cylinder to retract electrodes is longer than the hold time needed for resolidification, etc. In these cases it would be desirable for the control to furnish what amounts to a *negative* hold time setting. This would mean that the valve solenoid would be de-energized before the end of the weld time. A feature of this sort might not be useful in a majority of applications but would help to get the most out of a large, slow operating tool.

Off time is the interval in repeat welding during which the electrodes are off the work. The control setting is determined by the interval required for the operator to move the tool to the proper position for the next spot. The operating stroke of the gun on repeat welds in a series is reduced if the off time setting is shorter than the interval required for the electrodes to release the work and retract through the full stroke. Therefore, the short operating stroke on repeat welds mentioned above is accomplished merely by reducing the off time setting. This can be done on any of the conventional sequence weld timers. However, the conventional controls do not provide the "dual" squeeze time setting which has been shown to be desirable and which bears a definite relation to off time.

In order to be certain of covering a wide range of gun welder applications, each element of a sequence weld control should be capable of time settings down to a very small value. The typical three cycle minimum provides for a theoretical top operating speed of 300 welds per minute. However, this rate is possible only if no one interval in the welding cycle exceeds three cycles and if there is no time lost in transition from one interval to the next. Something more than the conventional control will often be necessary to make the tool and valve system perform at maximum practical speed. Time settings of less than three cycles should be possible and will be particularly useful in cases where the actual time setting must be reduced to compensate for slow action of other parts of the equipment.

Repetitive timing accuracy is of particular importance on gun welding applications where the operator must handle a heavy tool. Experience has shown that slight inaccuracies of conventional nonsynchronous timers tend to accumulate and destroy the operating "rhythm" of the tool. Operators complain that their tools are "bucking" and are very hard to handle. Extra effort spent in "fighting" the tool tires the operator and reduces efficiency.

This operating rhythm is also important for proper spot spacing. In many cases the operator actually leans with almost full weight on the tool, knowing that the off time setting, the inertia of the tool and his body pressure will result in the proper spacing. If the operating rhythm is erratic, however, he never knows when to expect the movement of the tool, and even spacing is impractical except at very low speeds. Experience indicates that the only way to eliminate this deficiency is to have the repetitive accuracy of the pressure cycle virtually perfect.

Design Considerations

This paper is concerned with the development and operation of a new high-speed sequence weld timer having the desirable features described above. It is intended specifically for the repeat operation characteristic of gun welders used in high-production setups. For easy reference it will be called Type FG-1. A synchronous motor drive for cam-operated contacts was selected as a basis for the design. Several advantages of this type drive are:

1. Consistent operating rhythm is assured by controlling all timing intervals with a single revolution of the synchronously rotating cam shaft.
2. Synchronous characteristics permit minimum time settings for each interval without adversely affecting weld quality. Even the effect of transients in the welding current is minimized because it is consistent from one weld to the next.
3. No time can be lost in transition or sequencing from one time interval to the next.
4. If desired, time intervals can be made to overlap, permitting the equivalent of a negative time setting.

Another characteristic of motor drive appeared to be a disadvantage at first, but later developed into a desirable feature of the equipment. The cam shaft speed must be selected through proper combination of gears on motor and cam shafts. Each revolution of the cam shaft must be divided into squeeze, weld, hold and off periods. This division is made easy by calibrating the adjustments in per cent of one revolution. Table 1 gives the total number of cycles (of 60-cycle line frequency) per revolution at each operating speed available. This arrangement permits changing any of the time settings slightly without changing the total time for a weld. Operating speed remains the same after minor adjustments, and operators become accustomed to that speed. This characteristic is a distinct advantage in that tool speed can be adjusted to work conditions and will not change. The operator always knows what to expect and gains confidence through experience.

A fifth timing period was added to the conventional four in developing the Type FG-1 device. It was found to be a simple and practical means for providing a squeeze time on the first weld of a series longer than for repeat welds in the same series. This extra timing period has been called "squeeze delay." Squeeze time on the first

Table 1—Operating Speeds for Type FG-1 Timers

Welds per Minute	Cycles per Weld*	Cam Shaft R.p.m.	Motor R.p.m.
100	36	100	300
109	33	109	300
120	30	120	300
138	27	138	300
150	24	150	300
164	22	164	300
180	20	180	300
200	18	200	300
218	16½	218	300
240	15	240	300
266	13½	266	300
300	12	300	300
327	11	327	300
360	10	360	300
400	9	400	300

* Cycles of 60-cycle frequency.

weld results from the sum of the squeeze delay period and the regular squeeze period. The two settings are independently adjustable so that the gun installation can be adjusted for the maximum practical repeat welding rate without regard to the initial operating stroke of the tool.

A simple example will show how this feature can speed up the gun welder operation. Assume that a 4-cycle weld time setting is required while settings for hold and off times must be 6 cycles and 8 cycles, respectively. Assume also that the squeeze time setting would need to be 20 cycles, to allow for a 3-in. stroke on the first operation but could be reduced to 6 cycles on succeeding operations because the short off time would allow only $^1/_2$-in. stroke. With conventional control the squeeze time setting would be 20 cycles for each weld and the total time for a weld would be 38 cycles, corresponding to 95 welds per minute. With the new type controller, every weld but the first would require only 24 cycles, thus increasing the rate to approximately 150 welds per minute.

An important objection to most motor-driven timers heretofore available had been the necessity for considerable maintenance attention during the rather limited useful life of the equipment. Trouble was encountered due to excessive wear characteristic of continuous motor operation at high speed. In other types, a magnet-operated clutch was used, but this also was a frequent source of trouble. Stopping the motor at the end of each series of welds in repeat operation would permit direct coupling of cam shaft to motor without subjecting parts to unnecessary wear.

From previous experience, it was obvious that the starting and stopping of the motor must be accomplished within a minimum time. Otherwise, an operator might be disturbed by having to wait for the control to restart between two series of welds. Also the time between depression of the initiating thumb switch and completion of the first weld would need to be constant. Otherwise, the operator would not be able to anticipate tool reaction and benefit by consistent rhythmic response. This

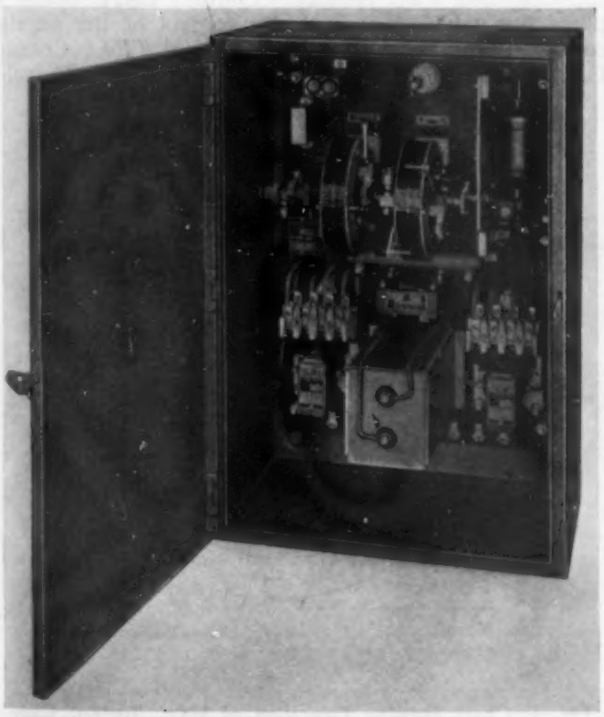

Fig. 1—Type FG-1 Synchronous Motor-Driven Timer in Cabinet

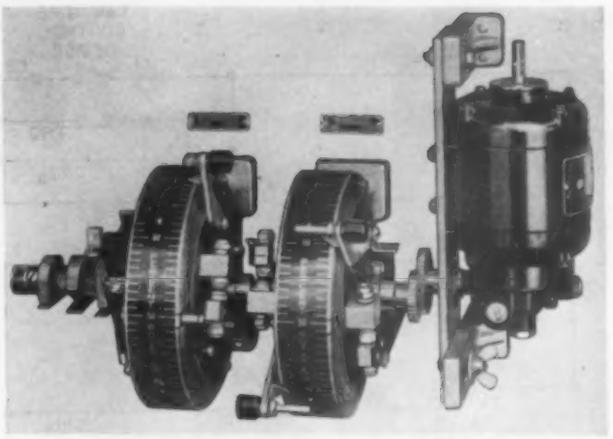

Fig. 2—Close-Up of Motor, Cam Shaft and Contact Assembly

requirement meant that the motor must always stop in the same position and must have consistent acceleration characteristics.

To meet these requirements, a capacitor type synchronous motor was selected. Its accelerating characteristics proved to be such that the cam shaft would be up to more than 90% of synchronous speed at the beginning of the first weld time under extreme conditions, such as with minimum squeeze delay and squeeze time settings at an operating speed of 400 welds per minute. Under normal conditions, it was found that the motor would pull into synchronism considerably before the first weld time began.

In order to stop the motor quickly and at a predetermined point with respect to cam shaft revolution, a new braking method was developed. Mechanical braking was ruled out because of wear and maintenance difficulties. Instead an electrical braking scheme was devised to give the motor windings a heavy, undirectional pulse of current (accomplished with only two additional control contacts and a large capacitor). Performance was found to be such that the motor and cam shaft would stop completely in less than one cycle (of 60-cycle line frequency) after opening of the cam-operated contact which de-energizes the motor circuit. Details of the braking system will be described in later paragraphs.

Early in the design effort, it was realized that two control relays would be required. One would be used to start the motor and provide a holding circuit for the necessary nonbeat operating feature which insures that once a welding cycle is begun, it will be carried through to completion without depending on the operator to hold the initiating switch closed. The second relay was needed to provide the squeeze delay period for the first weld and eliminate it for succeeding welds in a repeat series. With the aim of increasing mechanical life and reducing maintenance, the circuit was arranged so that both relays close to start a series of welds, open to stop the series but remain closed during the repeat operation. Thus relay life is multiplied by the average number of welds in a series, and only the cam-operated contacts function for each weld in the series.

Timer Description

The Type FG-1 timer in its present design state is illustrated in Figs. 1 and 2. The synchronous motor, the cam-operated contacts, the relays and accessory equipment are all visible. Contacts are located one on each side of two large drums, with scales calibrated in per-

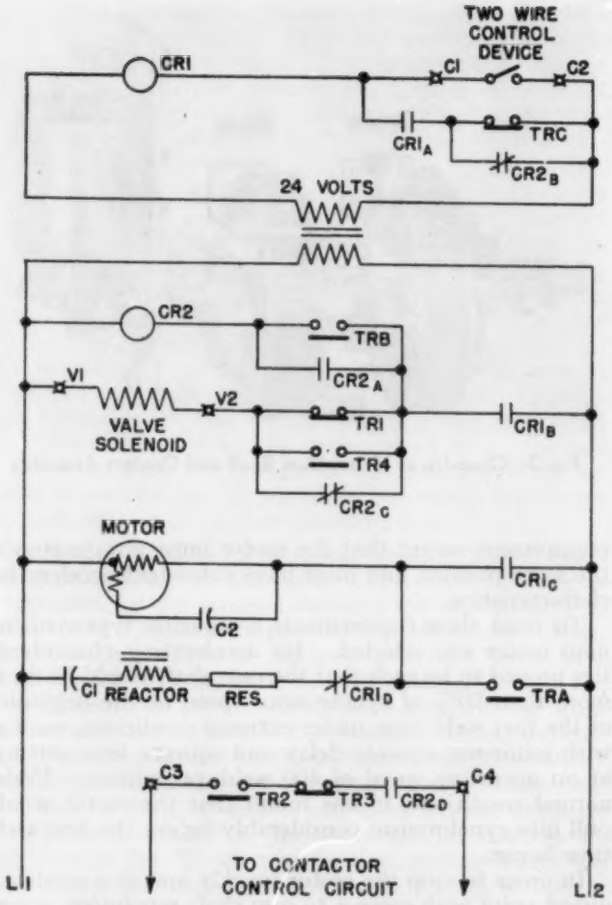

Fig. 3—Schematic Diagram for FG-1 Timer

centage of one revolution. These same drums contain the cam shaft ball bearings and they also provide the bearing surfaces for disks on which the adjustable cam-operated contacts are mounted. Three of the cam-operated contacts are provided with readily accessible adjusting levers, and the fourth remains fixed at 0% point of the cycle.

At the left-hand end of the cam shaft are three auxiliary cam-operated contacts identified as *TRA*, *TRB* and *TRC*. These three contacts are used for sequencing during the starting and stopping operation for a repeat series of welds. Indirectly, contact *TRA* determines the squeeze delay time since it governs the point on the cam shaft revolution at which the control stops when de-energized. The squeeze delay time is determined by the amount of rotation required from this adjustable starting point around to the point where main cam contact *TR1* closes—the point calibrated 0% on the adjusting scale and corresponding to the start of the normal squeeze time setting.

The drive motor is mounted on a swinging bracket to allow proper meshing of various size gears. A variety of gear changes are possible so that 15 different operating speeds can be selected. Table 1 gives the combinations available on the standard model, and corresponding operating speed data.

Other panel equipment necessary for sequencing, starting and stopping the cycle, etc., includes two high-speed control relays, a control transformer, a phase-shifting capacitor permanently connected in series with one motor winding and components of the capacitor braking circuit. This braking circuit requires a large, high-voltage capacitor with a series resistor and reactor. All of the components are mounted on the ebony asbestos panel with terminals for eight external connections.

Squeeze, weld, hold and off time adjustments can be made while the timer is in operation by means of electrically insulated levers which are positioned with respect to calibrated reference dials around the circumference of the drums. The calibration is in per cent of rotation, with one revolution of the cam shaft being taken as 100%. If desired, the percentage readings may be easily converted to cycles of line frequency by multiplying times the number of cycles equivalent to one revolution at the operating speed. See Table 1 for these data.

Squeeze delay time adjustments are easily made by positioning the *TRA* contact operating cam at the extreme left-hand end of the cam shaft. A set screw is provided for this purpose and there is a calibrated dial mounted on the retaining collar at the end of the shaft. The squeeze delay period may be adjusted through a range of from 25 to 75% of one revolution. As explained above, it occurs only on the first of a repeat series of spot welds.

Sequence of Operation

A schematic diagram for the timer is shown in Fig. 3. The complete sequence of operations is as follows:

Operation of the initiating push button (usually mounted in the handle of the welding gun) picks up relay *CR1*. Contact *CR1A* forms a holding circuit through normally closed *CR2B* contact. Contact *CR1B* energizes the valve solenoid through parallel normally closed *CR2C* contacts and *TR1* contacts. Contact *CR1C* starts the motor, while normally closed contact *CR1D* opens up the capacitor braking circuit.

After the cam shaft has rotated from its starting position to the 0% rotation point (as indicated in Figs. 4 and 5) sequencing contact *TRB* closes, picking up relay *CR2*. Contact *CR2A* provides a holding circuit, Contact *CR2B* opens and makes the continued holding in of relay *CR1* dependent on the initiating push button and cam-operated *TRC* contact. Contact *CR2C* opens to place the valve solenoid under control of the parallel combination of cam contacts *TR1* and *TR4*. Contact *CR2D* closes to make possible energization of the weld-

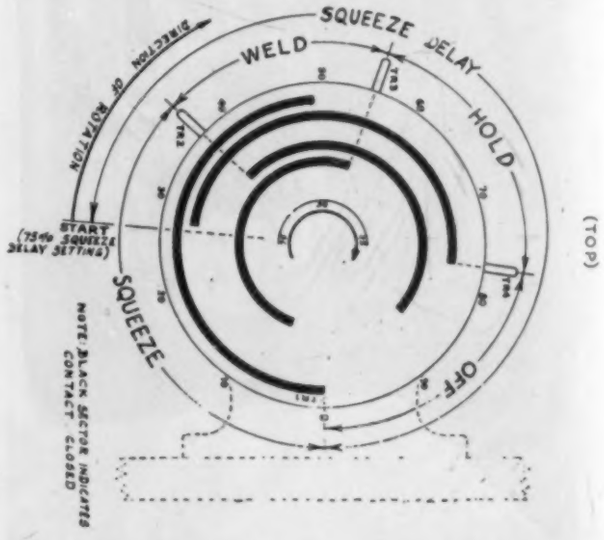

Fig. 4—Chart Showing Operation of Main, Timing, Cam-Operated Contacts

ing contactor at any time during which the cam-operated *TR2* and *TR3* contacts (connected in series) are both closed.

It will be noted that the relay operation is such that only *CR1* is energized during the first portion of the revolution from the starting point around to the 0% point. This is the squeeze delay period and the occurrence of a weld time or an off time is prevented by contacts *CR2D* and *CR2C*.

As soon as the 0% rotation point is reached, however, relay *CR2* picks up and thereafter the panel goes through its normal sequence of squeeze, weld, hold and off times until it is stopped.

Cam-operated contacts *TR1*, *TR2*, *TR3* and *TR4* operate as indicated in Fig. 4. It can be seen that the valve solenoid will be energized at all times during which either *TR1* or *TR4* contacts are closed. Therefore, off time occurs after *TR4* opens and until *TR1* closes.

Weld time occurs only when both *TR2* and *TR3* contacts are closed. The weld time is indicated as the overlapping portion of the black *TR2* and *TR3* sectors in Fig. 4. Therefore, it can be seen that squeeze time begins when *TR1* closes and ends at the beginning of weld time when *TR2* closes. Hold time begins at the end of weld time when *TR3* opens and continues until *TR4* opens to begin off time.

As long as the initiating push button remains closed, the above cycle will be continued. However, when the push button is released, continued energization of *CR1* depends entirely on sequencing cam contact *TRC*. As indicated in Fig. 5, *TRC* remains closed except for a 15° interval beginning at 85% rotation. After the push button is released and the control rotates to the 0% point, *CR1* will drop out to begin the stopping operation.

As *CR1* drops out, contact *CR1B* opens to drop out relay *CR2* and prevent further energization of the valve solenoid. Contact *CR2D* in turn opens to prevent further energization of the welding contactor. Contact *CR1C* opens to place energization of the motor under control of sequencing cam contact *TRA*. At the same time, contact *CR1D* closes to energize the capacitor braking circuit.

The motor continues to run until the cam shaft advances to the point where *TRA* opens (see Fig. 5). When

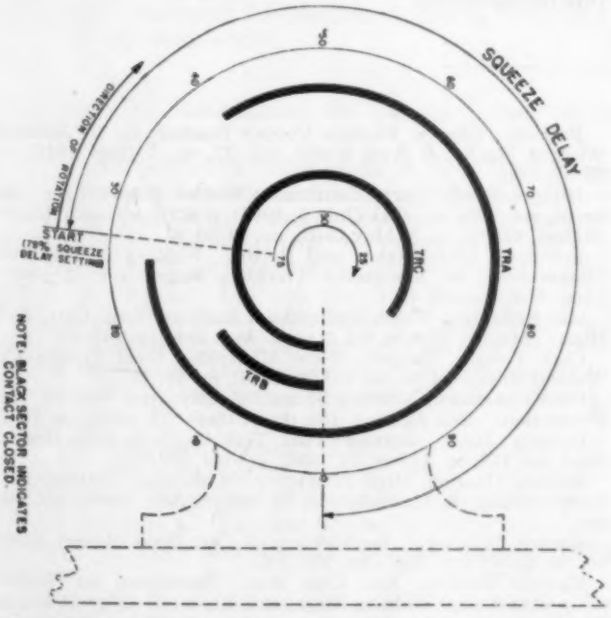

Fig. 5—Chart Showing Operation of Auxiliary, Sequencing, Cam-Operated Contacts

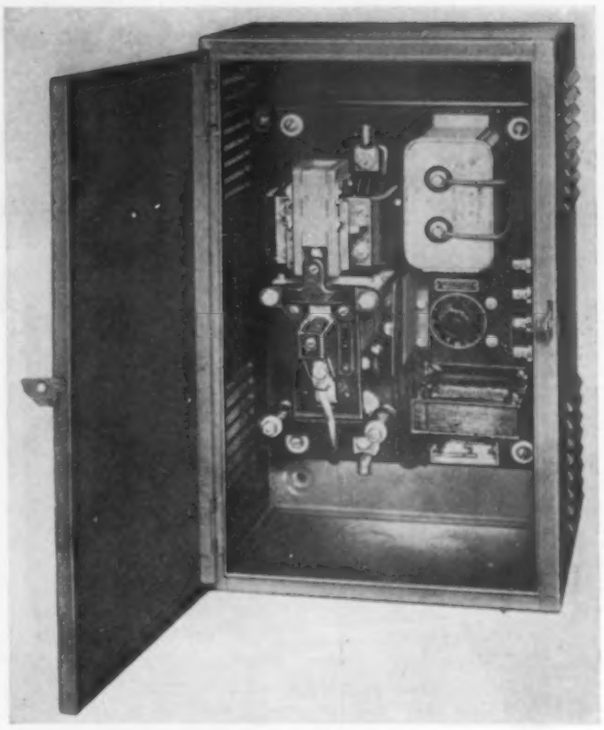

Fig. 6—Synchronously Interrupting Contactor

this contact opens, no further power is delivered to the motor and the charge in the large braking capacitor is delivered to the motor as a heavy d.-c. braking pulse. This braking pulse is sufficient to stop motor and cam shaft rotation during the short interval before contact *TRA* could reclose. This completes the repeat welding cycle and the control is left again at the starting position ready for initiation of another series of spots.

Capacitor Braking

As indicated in the above sequence of operation, the capacitor braking circuit is energized just previous to the moment when it is needed to stop the motor and cam shaft. It could be energized continuously except that larger, continuous duty components would be required. The intermittent energization scheme was adopted to effect savings in size and cost.

When cam contact *TRA* opens and removes power from the motor, it is essential that the braking capacitor have a full charge. Otherwise, since energization is from an a.-c. circuit, the possible variation would be from full charge to zero charge. If the charge left on the capacitor is not consistently near its peak value, it would not be sufficient to brake the control to a stop before reclosing of *TRA*. Such a condition would mean that the motor would again receive power from the line and another revolution would be made.

In order to achieve full charge on the condenser, it has been arranged that *TRA* will effectively open at a zero point in the a.-c. current wave for the load represented by the parallel circuit of motor and braking capacitor. This is done by adjusting the *TRA* contact gap and the circuit constants so that an arc is always held at the *TRA* contact until the current goes to zero. The reactor and resistor are included in the braking capacitor circuit to assist in holding the arc at *TRA* and to provide the proper time delay and damping effect for the transfer of braking capacitor energy into the motor winding.

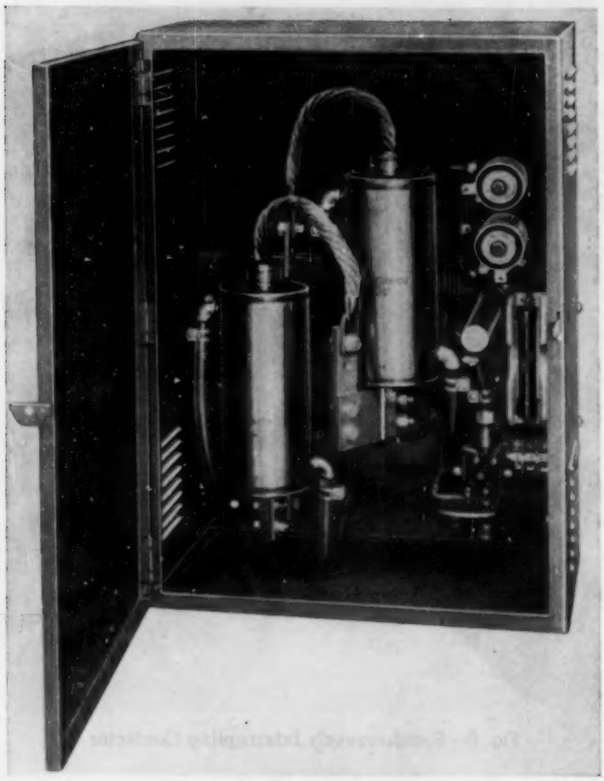

Fig. 7—Electronic Contactor

Contractors

A power contactor is required with the FG-1 timer to make and break the primary circuit of the welding transformer. The contactor must be capable of high-speed operation while handling currents characteristic of welder service.

Either magnetic (Fig. 6) or electronic (Fig. 7) contactors can be satisfactorily applied. In the case of the magnetic contactor, however, use of the synchronously interrupting type is desirable to minimize contact heating and prolong life. The synchronous interrupting feature causes the contact tips to open at a zero point of the welding current wave. This eliminates arcing and insures that the contactor will conduct full current until the tips open and zero current thereafter. Increased contactor ratings are possible due to absence of arc heat, and longer contact tip life results. Maintenance is less frequently required. Time required for closing and opening the magnetic contactor is no disadvantage since it may easily be compensated for by the setting of the cam-operated contacts on the timer.

Electronic contactors must be used if electronic heat control is desired. They are also recommended for installations involving very heavy currents or unusually short weld times at very high speeds.

Field Experience

Over 200 of the Type FG-1 timers were installed in automobile body production plants in 1940 and 1941. During the war these units were used on a variety of gun welding jobs, some of which involved stainless steel fabrication. Most of the original quantity are now back on the body production job. They are still in good, serviceable condition and maintenance requirements have been generally slight.

Conclusions

To obtain increased welding speeds and proportionate reductions in fabrication costs, it is necessary to employ a sequence weld timer designed to keep squeeze, weld, hold and off periods each as short as possible without sacrificing weld quality. Since many jobs require a longer stroke for the first than for repeat welds in a series, the control also should be capable of giving a longer squeeze time for the first weld. A practical method of accomplishing this is to provide a "squeeze delay" time which adds to the regular squeeze time on the first operation only.

For greatest operator efficiency, the tool must perform with a very consistent rhythm; i.e., its repetitive accuracy must be almost perfect. Timing from cam-operated contacts driven by a synchronous motor meets this requirement.

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(*Continued on page 1108*)

Design and Production Control of Silver Alloy Brazed Joints in Aircraft Structures*

By H. A. Smith† and P. A. Koerner†

Introduction

SOME two years ago, following a preliminary survey of design and fabrication methods, it was anticipated that attractive economies might be realized through the use of silver alloy brazing for the construction of landing gear. Consequently, an experimental program was initiated to determine the extent of the possibilities for using brazing methods of joining.

It was evident before any work was started that an alloy requiring as low a brazing temperature as possible must be chosen because it would often be necessary to join hardened steel components whose strength would be altered by the tempering accompanying brazing heat. It would further be desirable to use greater clearances than had hitherto been considered practicable. After a period of preliminary experimental work it was evident that all brazing alloy would have to be preplaced, that the alloy should not be expected to flow against gravity and that the amount of silver alloy used for a joint would have to be a design factor to be carefully considered. Information was obtained from the investigation for writing design, procedure and operator certification specifications. Although these specifications have been approved by the Civil Aeronautics Administration and use of silver brazing has expanded beyond the original application on the Model 18 landing gear, investigation of the many phases of this method of joining is continuing and will remain active.

Procedures for Establishing the Use of Brazed Joints

Proper consideration being given to other design factors, optimum reliability must be incorporated in an aircraft structure. When brazed joints are to be used for the transmission of loads that are essential for the safe operation of the ship, great care must be exercised in their design, production and inspection. To satisfy one's self as well as the Civil Aeronautics Administration that brazed joints will have adequate strength and that they can be reproduced in production, two methods of approach may be taken, either of which will accomplish the same end.

If only a limited number of different joints are envisaged and if development time is critical, a method of approach may be employed that will require a minimum of time and effort. This method will yield arbitrary restrictions on the manufacture of joints developed under it. For example, from general knowledge, a joint may be designed with a given area between faying surfaces, a given clearance and components made of a given grade of hardened and tempered steel. If a sufficient number of such joints are made to determine the reproducibility of the joint and the strength is satisfactory, this particular joint may receive approval. Other joints may be individually approved through a similar procedure. If a general use of brazing is anticipated, this method is slow, expensive and does not develop definite knowledge concerning basic principles and their practical limits.

If a wide use of silver brazing is anticipated, as was the case in our organization, a well-conceived and executed program of engineering development should be initiated to determine the underlying essential facts needed for preparing general specifications for design, production and inspection of joints. If such information is systematically developed and supported by data the specifications may be approved before plant production starts. The systems necessary for the satisfactory coordination of a production brazing program can be anticipated and provision made for them before production work begins.

I. Principles of Design

A proper design specification should incorporate all information and auxiliary instructions covering the essential factors that are necessary for the design of a satisfactory joint. The designer must be able to design a joint with confidence that the joint will have a minimum known strength when it is made in production.

Constant Factors

In the composition of the design specification there are certain factors with which the designer is concerned and which affect the strength of the joint but which are not subject to change by him. Such factors must be fixed and will apply similarly to all joints. These items are:

*1. The silver brazing alloy used must conform to the requirements of Federal Specification QQ-S-561-d, Class 4.

*2. The flux used must conform to Air Corps Specification 11316-A.

3. The finish on all parts machined for brazing must have a smoothness of at least 100 microinches, rms.

*4. All joint components must be chamfered on the edge adjacent to the faying surfaces. See Fig. 1.

5. All brazing alloy needed for a joint is preplaced before brazing.

6. All brazing alloy rings used in any one joint shall be of the same size.

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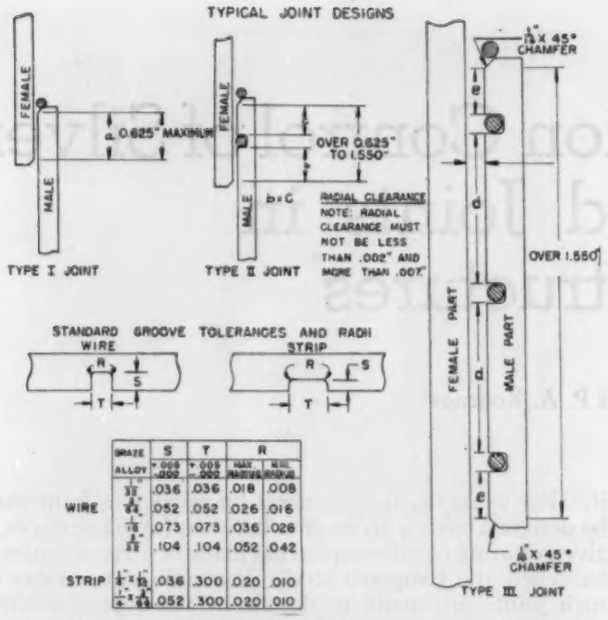

BRAZE ALLOY	S	T	R	
	+.005 -.002	+.005 -.002	MAX RADIUS	MIN RADIUS
WIRE 1/32"	.036	.036	.018	.008
WIRE 3/64"	.052	.052	.026	.016
WIRE 1/16"	.073	.073	.036	.026
WIRE 1/8"	.104	.104	.052	.042
STRIP 1/16" x 1/16"	.036	.300	.020	.010
STRIP 1/16" x 1/8"	.052	.300	.020	.010

Fig. 1—Design Criteria for Silver-Brazed Cylindrical Lap Joints for Primary Structures

*7. Groove shapes and sizes for the preplacement of alloy rings are standardized. See Fig. 1.

8. Molten brazing alloy must always flow with gravity. It is never expected to flow against gravity.

9. All joints must be lap joints of the male and female type such that the principal stresses on the silver alloy are shear stresses. A design may be a combination of a lap and butt joint, but the strength of the joint is calculated only from the lap portion. See Fig. 1.

10. Only joints between components of ferritic alloy constructional steels are to be considered.

Variable Factors

Certain design factors may vary from joint to joint and are subject to change by the designer. In this way freedom is provided for the creation of designs to suit a variety of conditions. These variable factors with their limiting conditions are as follows:

*11. Radial clearances between the faying surfaces of joint components must be between 0.002 and 0.007 in. See Fig. 1.

*12. The molten brazing alloy from any one preplaced ring must not be expected to penetrate a distance of more than 0.625 in. of faying surface. See Fig. 1.

13. A distinction is made between three different types of joints. In a Type I joint one preplaced alloy ring is used and it must fill the joint and form both fillets. In a Type II joint two preplaced alloy rings are used. Each ring must fill part of the joint and form one fillet. In a Type III joint any number of preplaced alloy rings greater than two are employed. The rings nearest the outside or on the outside of the joint fill part of the joint and form one fillet. The rings more remote from the ends of the joint only fill their part of the joint. See Fig. 1.

*14. A selection may be made from stocked brazing wire and strip of the following cross-sectional sizes: 0.031-in. diameter wire; 0.047-in. diameter wire; 0.063-in. diameter wire; 0.094-in. diameter wire; 0.250- x 0.031-in. strip; 0.250- x 0.047-in. strip. See Fig. 1. Figure 2 is a reproduction of a drawing that permits designation of brazing alloy wire rings preformed by a code number.

*15. A suitable steel must be specified for the joint components. The selection of steel will depend upon the strength after brazing for which the parts are designed.

The referenced items (*) in the above two classes of design factors are those that must appear as part of the design drawing for production work.

To determine the cross-sectional size of alloy rings to be used in a joint, the designer must have from his design the following information:

1. The maximum radial clearance possible between the male component at the minimum outside diameter tolerance limit and the female component at the maximum inside diameter tolerance limit.
2. The maximum distance of flow expected of the alloy rings in the joint.
3. The type of joint.

With this information the designer, from a series of tables, determines the cross-sectional size of alloy rings necessary for the joint he has designed. These tables are based on the verified assumptions that the volume between faying surfaces is completely filled, the chamfered volume is completely filled and that a uniform external fillet of the same size as the chamfer is formed.

Through the use of a design specification embodying the above discussed principles together with the specifications discussed below, a designer can design a joint with confidence that it will have a minimum strength.

II. Principles for Making Brazed Joints

A proper procedure specification must clearly present all of the factors which must be controlled to make an acceptable joint. It should further provide for limitations within which each factor must be controlled. The

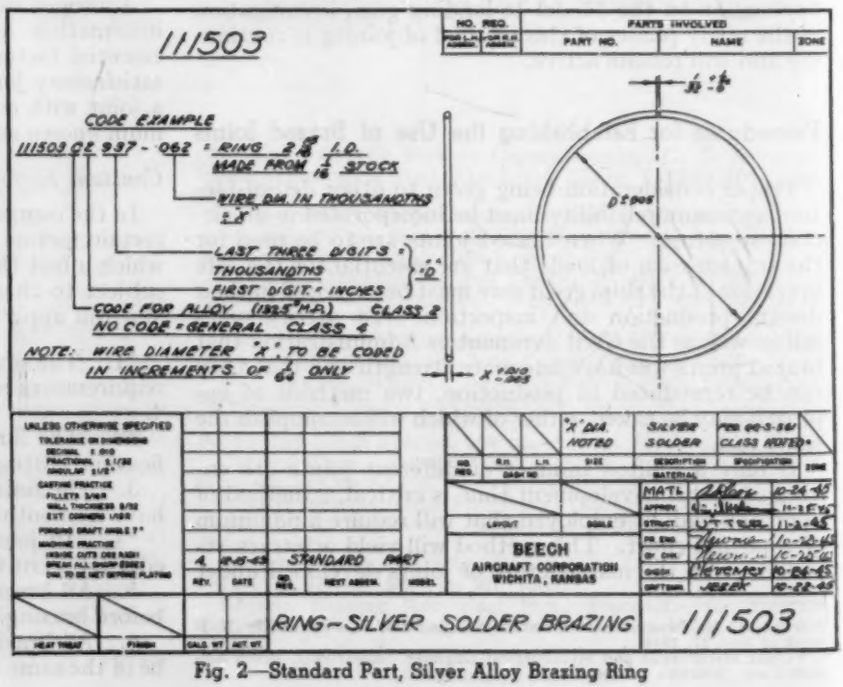

Fig. 2—Standard Part, Silver Alloy Brazing Ring

purpose of a procedure specification is to enable the operating personnel to make joints in production that will have at least the minimum strength for which they were designed. In the specification written for the guidance of brazing personnel the essential precautions to be taken may best be grouped into four sections corresponding to the natural sequence of making brazed joints.

A. Preparation and Assembly

1. For the silver brazing alloy and flux used, proprietory products are specifically stipulated which meet the material specifications of Paragraph I-1 and I-2.

2. On machined finishes a surface smoothness of at least 100 microinches rms. is required. In certain cases, cold-drawn tubing may be brazed without machining if the surface is properly cleaned.

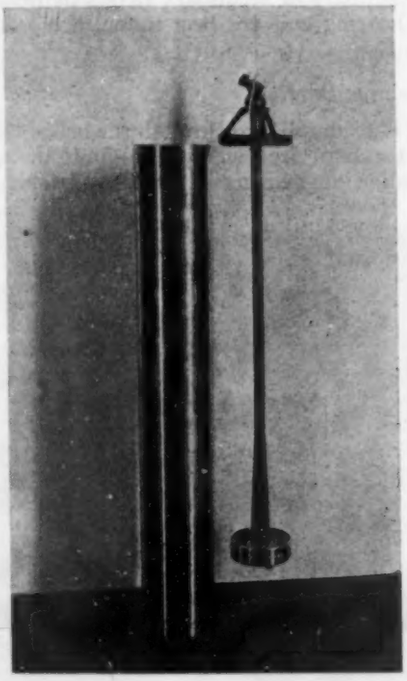

Fig. 3—Model 18 Landing Gear Piston, Metering Pin Support and Brazing Jig

3. The surfaces to be brazed of component parts must be free from heat scale and oxidation, rust and corrosion products, oil and paint and all loosely adhering material of any sort. Alloy rings must be free from perceptible oxidation and from paint, oil and all adhering foreign material. Brazing must be completed within 2 hrs. after cleaning, and handling shall be done in such a way as to retain the surfaces in the cleaned condition until brazed.

4. Flux shall be applied to all surfaces to be brazed and to a distance of at least $^1/_2$ in. beyond the maximum extent to which the silver alloy is expected to flow. In fluxing joints containing preplaced rings within the joint, the component surfaces shall be fluxed first and then the rings are fluxed and placed in the grooves. The surfaces containing the grooves and rings are then finally fluxed again to insure complete coverage of all interior surfaces by flux.

5. Where at all possible, jigging should be used for holding and supporting the components of a joint. Proper fixtures must be used to assure the alignment of the components in the finished joint. Experience has shown that when very close tolerances are required in the

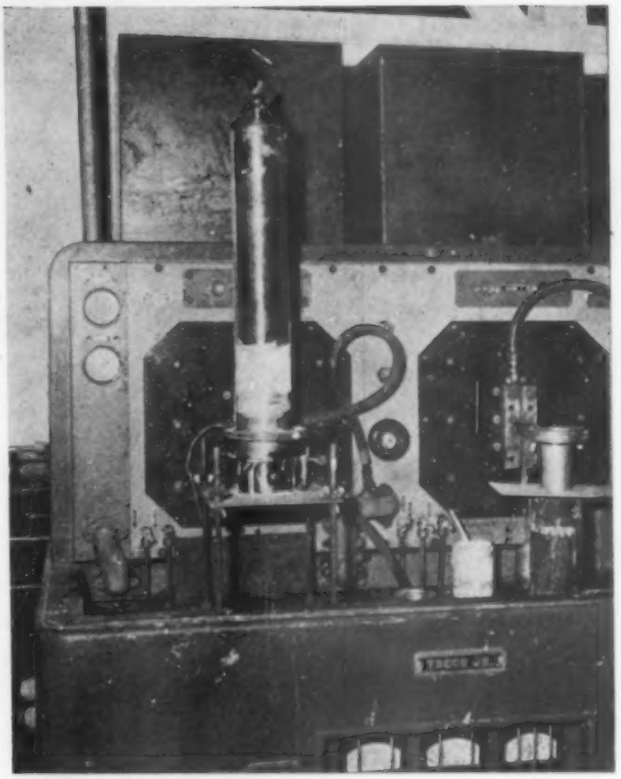

Fig. 4—Assembly of Fig. 3 Following Brazing by Induction Heating

finished assembly, either very small clearances between the components in the joint together with very accurate jigging is required, or the brazed assembly must be machined after brazing. Three fundamental principles relative to jigging are recognized.

(*a*) All joints must be made in such a position that gravity will aid in the flow of flux and brazing alloy equally to all parts of the joint. Brazing alloy must never be expected to flow against gravity.

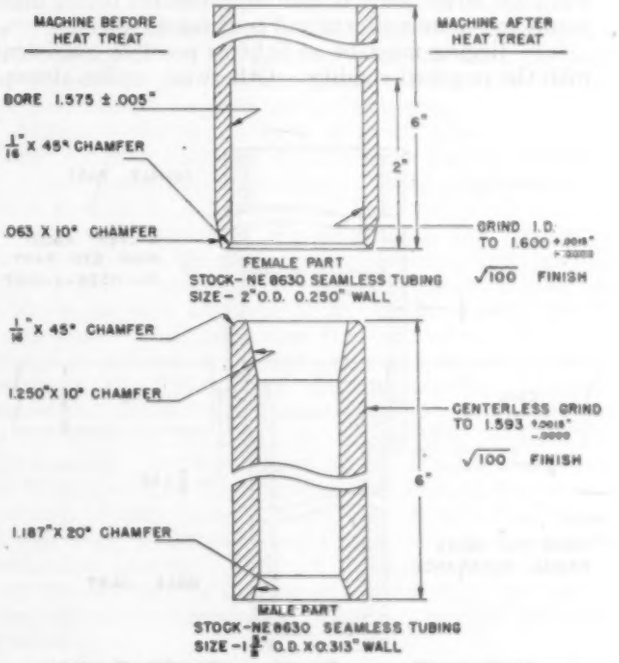

Fig. 5—Certification Test Specimen Components

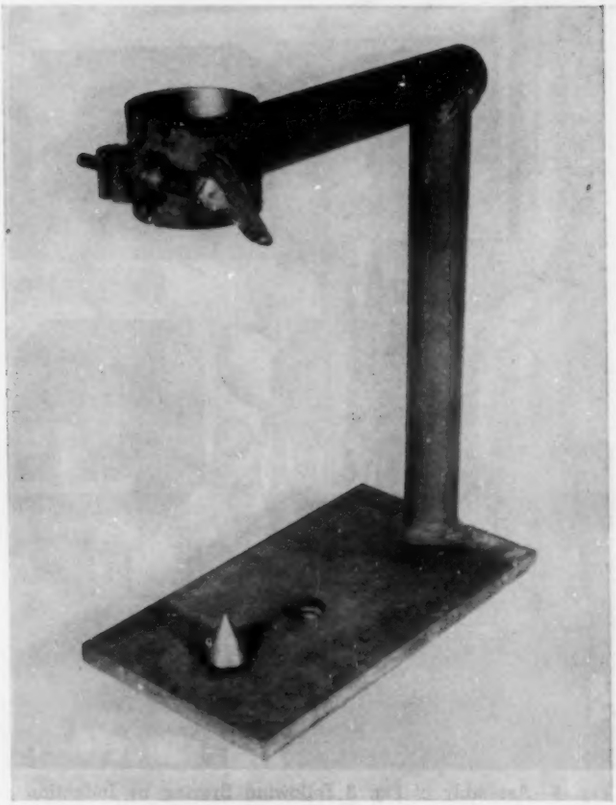

Fig. 6—Jig for Certification Test Joint

(*b*) It is not usually practicable to rigidly clamp both components of a joint in a jig and to expect consistently good joints and good alignment of the parts after brazing. If the one component is rigidly clamped and the other component is mounted on a ball or cone in alignment with the clamp, the joint not only can be wiped but the components center themselves nicely. Such an arrangement permits a uniform flow of brazing alloy through the joint. The wiping of joints, i.e., rotation of one component with relation to the other when the silver alloy is molten, promotes better filled joints and more uniform and continuous fillets.

(*c*) Jigging must be as light as possible consistent with the required rigidity. Otherwise, undue absorption of heat by the jig will cause nonuniform heating and may injuriously lengthen the heating time.

Figure 3 shows a heat-treated landing gear piston and a forged steel metering pin support with a center hole to be brazed within the cylinder. It may be seen that the metering pin support is supported from the top of the piston through a ball joint which permits wiping and also a lateral movement within joint clearance limits. The preplaced alloy ring may be seen in the metering pin support. A similar ring is placed on the top of the female part at the chamfer before brazing. Figure 4 shows the assembly of Fig. 3 in brazing position just following completion of the joint by induction heating.

Jig components that may come into contact with molten brazing alloy may be made of aluminum bronze since, with the flux employed, molten alloy will not adhere to this type of bronze. Jig components that come within the primary or secondary magnetic field from the induction heating coil are best made of a nonmagnetic material.

B. Heating for Brazing

Heating is accomplished through the use of the oxygen-acetylene torch or by electrical induction. As far as possible induction heating is used for brazing because such heating is more uniform and more readily controlled. It is especially required where heavy heat-treated steel components are to be joined. A more localized heating for a shorter length of time without overheating is of advantage when the as-brazed strength of heat-treated steel parts is to be maintained at some strength level above that of a normalized condition. Often electrical induction is advantageous for heating from the inside when joining large tubular components.

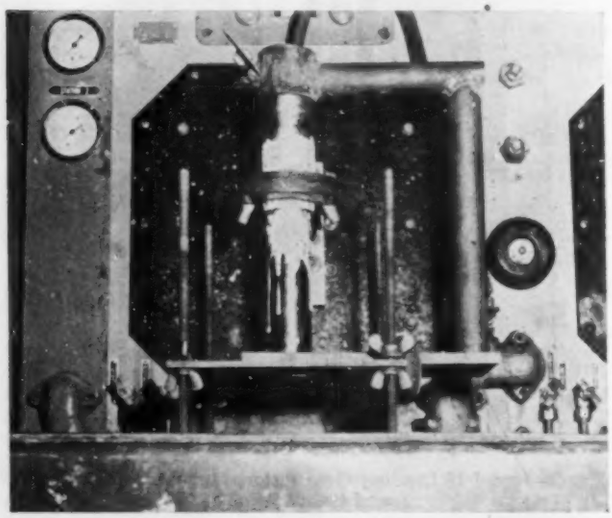

Fig. 8—Certification Test Joint Assembly Prepared for Induction Heating

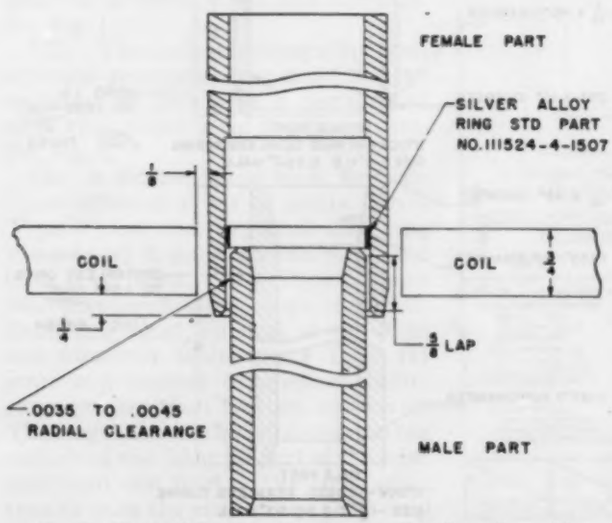

Fig. 7—Vertical Section, Certification Test Joint Assembly

Heating shall be sufficiently gradual at the beginning so that the flux is dehydrated in position with minimum run-off. This is somewhat more difficult to control when heating by induction since, by induction, the flux is first heated at the flux-steel interface, while in heating by torch the flux is first heated at the flux-air interface. After dehydration of the flux, the joint shall be completed as rapidly as possible to obtain a satisfactory joint without overheating the surface of the steel and without serious deterioration of the flux. Special care on the part of the operator must be used at this point when using induction heating. For an example of time of heat-

ing, the joint shown in Figs. 3 and 4 will take 5 to 6 min. to complete when brazing by induction. When heating by induction the flux does not deteriorate as rapidly and remains active longer than when heating by torch.

Actual temperature measurements made by thermocouple indicate that the temperature of the steel usually needed to complete a joint is between 1200 and 1250° F. In production no attempt is made to control the temperature. The operator uses whatever heat is necessary to satisfactorily complete the joint and the quality of the joint is determined by other criteria such as brazed component hardness and the formation of fillets. The operator judges the completion of the joint by the formation of satisfactory fillets.

C. Cooling and Defluxing

After cessation of heating the assembly is not moved until the flux has hardened. The joint is permitted to cool normally in air. Accelerated cooling is not permitted. All flux is removed in hot water as soon after brazing as possible and the assembly thoroughly dried in hot air.

D. Inspection

Joints shall be made only by an operator certified according to the following section. All joints shall have continuous uniform fillets at both ends of the joint. Heat-treated steel components shall be tested for hardness after brazing.

Certification Data Sheet

Aircraft Silver Alloy Brazing Operator

OPERATOR'S NAME R. G. Potter — CERTIFICATION SERIAL NO. 16

BADGE NUMBER 2-13058 — DATE 4-29-46

REFERENCE JOINT 41, P.S. 259	INSPECTOR
1. Parts machined OK.	
2. Parts set up OK, -- 5/8" lap.	
3. Brazed in accordance with P.S. 246	
4. Steel stamped with serial number. #16	
5. Fillets satisfactory.	
6. Outside diameter of male tube 1.591	
7. Maximum pounds pulled. 190,000	
8. Lap between chamfers. .667	HGR
9. Pounds per square inch. 42,000	HGR
10. Voids do not exceed 15% of faying surface. HGR	HGR
11. Rings cut and ground correctly.	HGR
12. Stenciled date, Operator's number, and Serial.	HGR
13. Rings stenciled with "J" on end nearest joint.	HGR
14. Rockwell readings -- Male part.	
½" from joint, minimum reading C36, is 36	HGR
1" from joint, minimum reading C39, is 41	HGR
15. Rockwell readings -- Female part	
½" from joint, minimum reading C29, is 31.	HGR
1" from joint, minimum reading C35, is 37	HGR

REMARKS Test Satisfactory

Inspector — Date 4-30-46 — Operator — Date 5-1-46

Welding Foreman — Date 5-1-46

Copies to Chief Inspector, Welding Foreman, Engineering Dept

Fig. 10—Operator's Certification Test Data Sheet

III. Certification of Operators

The specifications for design of joints and for the procedure for making joints were developed from many preliminary tests. During this testing program it became evident that the successful completion of joints between heat-treated steel components is to some degree dependent upon the proficiency of the man whose responsibility it is to heat the joint. Thus it becomes necessary to determine the proficiency of the brazing operator by suitable tests. The procedure to be followed in testing operator proficiency is incorporated in a specification "Certification of Aircraft Silver Brazing Operators." The essential features of this specification are here presented.

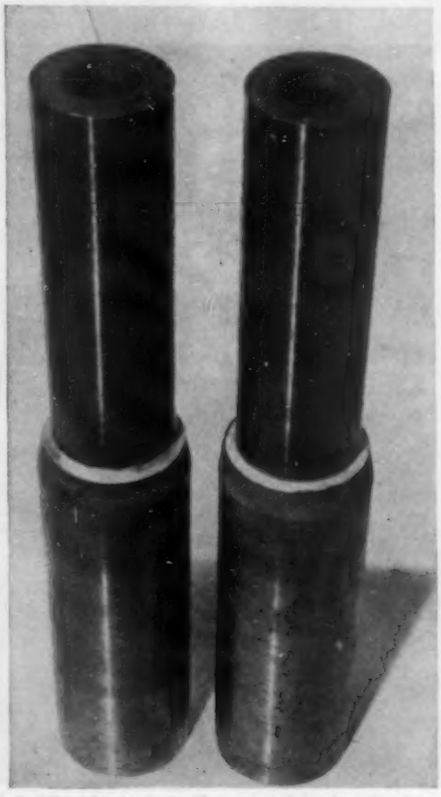

Fig. 9—Brazed Certification Test Specimens

Operators are certified for each of two methods of heating, oxygen-acetylene torch and electrical induction. To certify, an operator must make a joint by either or both methods of heating and the joint must meet minimum hardness, strength and alloy fillage requirements. The component parts of the joint, their heat treatment, the jigging and the joint requirements are identical for each method of heating. The actual operation of the heating equipment, the behavior of the flux, the heat generation and its flow into the steel need to be learned by the operator for each method of heating.

Figure 5 shows the type of steel, tube stock size, finished dimensions and surface finish for the certification test specimen components. These components are heat treated to a hardness of Rockwell C-42 to C-45 before final machining. Figure 6 shows the type of jig used for holding the parts during brazing. The clamp at the top holds the female part rigidly while the cone at the bottom, set in a ball bearing in the base, supports the male part. The clamp and the hole in the base into which is pressed the bearing are line bored to insure accuracy of alignment of the components. Figure 7 shows the proper disposition of the joint components, the silver alloy ring, 0.250 x 0.047 in., and the inductor coil for heating. For torch heating, the arrangement is exactly similar with the exception that no inductor block is needed. Figure 8 shows the jig, the assembled and fluxed components of the joint and the inductor coil ready for induction heating. Figure 9 depicts two certification test specimens after brazing and defluxing. The test on the left was torch heated. The one on the right induction heated.

An operator is certified when he can produce a joint

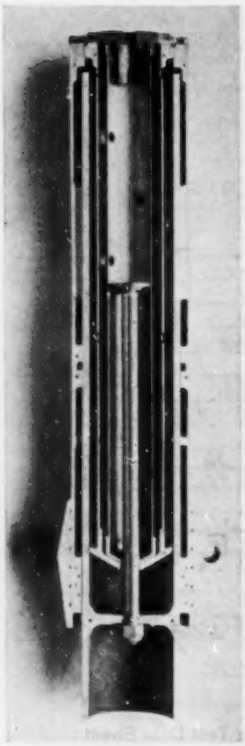

Fig. 11—Vertical Section, Main Landing Gear Hydraulic Shock Strut, Model 18, see Fig. 13

meeting the minimum requirements of the four following stipulations:

1. Fillets inside and outside shall be continuous and uniform and shall at their minimum extent completely fill both chamfers. Fillets on induction heated joints usually cover the flat portion of the female part next to the chamfer but do not extend down on the male part as far as on torch-heated joints. This is due to the difference in heating conditions where little heat is generated directly in the male part by induction but by torch heat is supplied directly to this component. See Fig. 9.

2. The breaking strength of the joint in shear shall be a minimum of 35,000 psi., calculated as indicated below. A review of the unit shear strength of joints through which operators have actually been certified shows a mean value of 43,200 psi., and a range of values from 38,200 to 52,300 psi.

3. The total amount of voids in the silver brazing alloy between the faying surfaces shall not exceed 15% of the area of the fayed surface of the male component. The maximum circumferential dimension of any void less than 0.250 in. in an axial direction, shall not exceed 0.750 in. The maximum axial dimension of any void less than 0.750 in. in a circumferential direction shall not exceed 0.250 in. A careful inspection of certification test joints shows that the mean percentage of voids occurring in the joints is 7 while the range is 2 to 13.

4. The minimum mean Rockwell C hardness value of the male and female parts taken at the center of the cross section at 0.5 and 1.0 in. from the joint shall be as follows:

	Distance from the Joint	
Part	0.5 In.	1.0 In.
Male	34	39
Female	29	35

From a review of the actual hardness values obtained from certification tests, we find the following:

	Distance from the Joint			
	0.5 In.		1.0 In.	
Part	Mean	Range	Mean	Range
Male	37.2	34.7–41.9	42.4	39.4–47.0
Female	33.2	29.0–37.0	40.0	36.2–44.7

These figures represent the as-brazed hardness of heat-treated NE8630 steel.

Figure 10 is a reproduction of a Certification Data Sheet upon which appears all necessary data for and is a record of an operator's certification.

Inspection of certification joints needs no further clarification except to explain the method used to calculate the strength of the joints. The load needed to break the joint is determined on a tensile testing machine at normal rates of loading. To obtain the unit breaking strength in shear the breaking load is divided by a test area. This area is determined by the circumference of the male part and the overlap distance between the roots of the chamfers, i.e., the axial length of the faying surfaces of the joint. The unit strength value thus obtained is cal-

Fig. 12—V-Brace Assembly, Main Landing Gear, Model 18

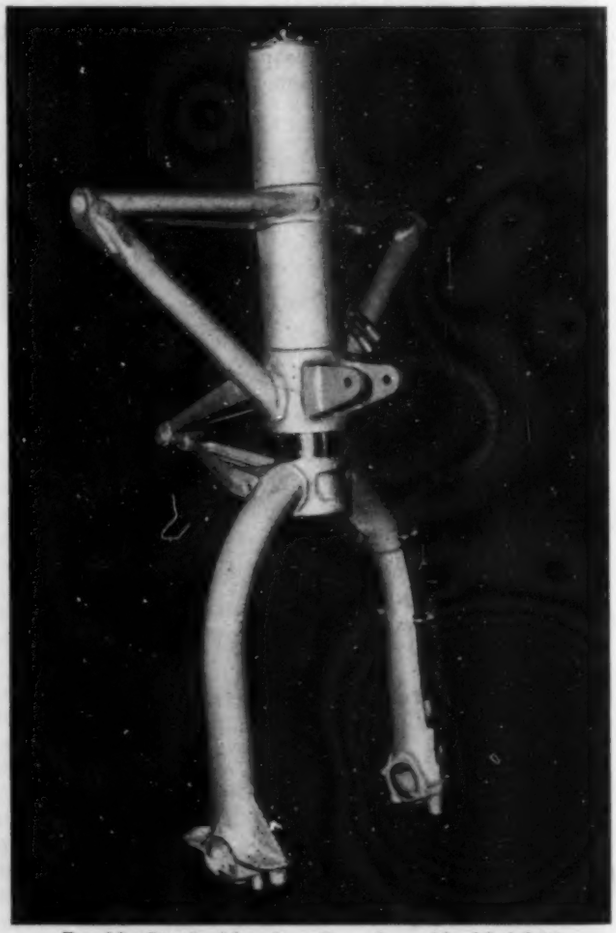

Fig. 13—Finished Landing Gear Assembly, Model 18

culated from the breaking shear load for the chamfer alloy, the fillet alloy and the alloy between the faying surfaces while the area employed includes only the area between the faying surfaces. This convention is followed to eliminate ambiguity in measurements which is a desirable characteristic of a specification. We have found that the unit strength of joints calculated in this manner is from 8 to 10% above the unit strength value of the joints without chamfers and fillets.

Provision is made for a program of recertification based upon the quality of joints currently being made by a certified operator and upon the continuity of time actually being spent in brazing operation by an operator.

Conclusion

The original application for silver brazing was on the Model 18 landing gear. Figure 11 shows a vertical section along the axis of a main landing gear hydraulic shock strut of this model ship. In this assembly there are 12 different silver-brazed joints. Figure 12 shows the welded heat-treated steel V-brace assembly that brazes to the outside of the hydraulic shock strut barrel of Fig. 11. Note the machined grooves for preplacement of silver alloy rings. In both of the joints shown 0.094-in. diameter round alloy wire is employed. Figure 13 is a view of a completed landing gear assembly ready for installation.

The design, procedure and certification specifications have been approved by the Civilian Aeronautics Administration. These specifications apply specifically to primary structures. There are an increasing number of applications where some deviation from the discussed design specification is permitted when a primary structure is not involved. Under these specifications silver brazing has been well integrated into design and production procedures within our organization. The use of silver brazing has steadily increased during the last 12 months until, at the present time, we are making 30 different joints on the Model 18 and 45 joints on the Model 35. Our consumption of brazing alloy has amounted to about 8000 oz. during the last year. The largest proportion of all joints made is between primary structural components, particularly in the landing gear. A small proportion of brazed joints is made between hardened and tempered steel components. In size these joints vary between 0.25 and 100 sq. in. of area on the faying surface and are made between steel parts with section thicknesses from 0.049 to 0.325 in.

Specifications are periodically subject to review in the light of results from the continuous investigation pursued on silver-brazed joints. Anticipated changes will permit the use of several grades of steel for heat-treated components, of butt joints and of a wider variety of brazing alloys. These and other changes will provide the designer with greater freedom and will open the way to the more extensive use of silver brazing as a major joining method for the production of aircraft.

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REQUIRED BY THE ACTS OF CONGRESS OF AUGUST 24, 1912, AND MARCH 3, 1933

OF THE WELDING JOURNAL, published monthly at Easton, Pa., for October 1, 1946.

State of New York } ss.
County of New York }

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Oxyacetylene Pressure Welding of Some Low-Alloy Steels and Non-Ferrous Alloys*

By Kenneth H. Koopman†

NUMEROUS investigations have been made during the past 8 years on oxyacetylene pressure welding of ferrous and nonferrous alloys at the Union Carbide and Carbon Research Laboratories, where it was initially developed. Since its development the process has been widely promoted by The Linde Air Products Co. This wide use has led a number of other investigators to devote considerable effort to the study of this process of welding.

The pressure-welding process is now being used with considerable success in joining various types of steel and some nonferrous alloys. One of the merits of the process is that it produces welds of excellent quality in the relatively high-strength low-alloy steels that are now being quite widely used. Because of the slow cooling and compression rates that accompany this welding process, there is no danger of weld cracking. Another advantage of the process is that low-alloy and plain-carbon steels can be welded to stainless steels of either the ferritic or austenitic type, with resulting good mechanical properties in the weld. Semiautomatic or fully automatic operation is required for pressure welding. For this reason, welds of uniform quality can be produced. The process can be applied in either the shop or in the field.

As has been described in the literature,‡ pressure welding of plain-carbon and low-alloy steels is accomplished by heating the weld zone to a welding temperature of 1200 to 1250° C. by means of a multiple-tip oxyacetylene heating head, and by simultaneously maintaining a pressure of approximately 2500 psi. on the abutting faces of the pieces being joined. The pressure is maintained until a predetermined amount of shortening has been produced. The quality of the weld depends upon the temperature and pressure used, the type of end preparation, the rate of gas flow and the total amount of shortening.

This paper contains data collected in the course of development of procedures for pressure welding various steels and nonferrous alloys. Included in this paper is a description of tests of pressure welds made in the following steels: S.A.E. X4130; 0.28% C, 1.60% Mn, 0.43% Mo steel; NE 8740; NE 8630; NE 8620; 5% Cr, 0.50% Mo steel; carbon-silicon spring steel.

Also included is a description of tests of pressure welds in the following nonferrous alloys: Nichrome (80% Ni–20% Cr); Monel; Everdur; Aluminum-Iron Bronzes; Tobin Bronze.

Table 1—Conditions for Pressure Welding of S.A.E. X4130 Tubing

Tube Size, In.	Total Time, Sec.	Pressure of Tube Wall, Psi.	Oxygen Consumption, Cu. Ft. per Weld
1.0 x 0.049	6	1000 for 5 sec. 3500 for 1 sec.	0.07
1.0 x 0.065	8	1000 for 7 sec. 3500 for 1 sec.	0.10
1.5 x 0.065	8	800 for 7 sec. 3000 for 1 sec.	0.14
1.5 x 0.083	11	800 for 10 sec. 3000 for 1 sec.	0.17

Table 2—Average Tension-Test Results of Pressure Welds in S.A.E. X4130 Tubing

Tube Size, In.	Condition	Yield Strength at 0.2% Offset (Lb. per Sq. In.)	Ultimate Strength (Lb. per Sq. In.)	% Elong. in 2 In.	Fracture
1.0 x 0.049	As-welded	104,200	123,300	4.0	2 in. from weld
	Normalized*	92,100	117,100	5.0	1/8 in. from weld
	Oil quenched and drawn†	165,800	177,000	3.6	In weld zone and tube
1.0 x 0.065	As-welded	95,400	120,300	5.7	3/4 in. from weld
	Normalized	92,000	134,400	8.2	1 1/2 in. from weld
	Oil quenched and drawn	166,000	182,100	3.2	1 in. from weld
1.5 x 0.065	As-welded	82,600	104,600	6.1	3/4 in. from weld
	Normalized	82,300	112,400	9.0	2 in. from weld
1.5 x 0.083	As-welded	100,100	119,500	6.1	1/2 in. from weld
	Normalized	92,700	129,800	5.6	3 in. from weld

* Normalized—900° C. (1650° F.) for 15 min. and air cooled.
† Heated for 20 min. at 900° C., oil quenched and tempered for 1 hr. at 450° C.

* Scheduled for Twenty-Seventh Annual Meeting, A.W.S., Atlantic City, N. J., week of Nov. 17, 1946.

† Union Carbide and Carbon Research Laboratories, Inc., Niagara Falls, N. Y.

‡ Bibliography at end of paper.

Low Alloy Steels

Pressure welds in S.A.E. X4130 aircraft tubing of various diameters with wall thicknesses from 0.049 to 0.083 in. were made in a semiautomatic machine. In Table 1 are listed the pressure-welding conditions as finally established. In Table 2 are listed average results

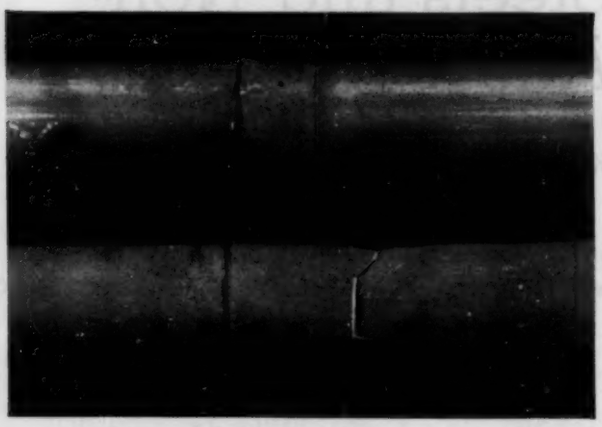


Fig. 1—Photograph of Pressure Welds in 1.0- x 0.065-In. S.A.E. X4130 Tubing After Tension Testing

The specimen on the left was tested in the as-welded condition, and the specimen on the right after normalizing at 900° C. (1650° F.).

Fig. 2—Photograph of Pressure Welds in 1.5- x 0.083-In. S.A.E. X4130 Tubing After Tension Testing

The specimen at the right was tested in the as-welded condition, while the specimen on the left was tested after normalizing at 900° C. (1650° F.).

of tension tests made on tubes in the as-welded, normalized and heat-treated conditions. It is interesting to observe that the tension fractures in the pressure-welded specimens occurred outside the weld zone. This indicates that the weld zone of tubing that had been pressure welded and subsequently normalized has tensile strength properties equivalent to those of the unwelded normalized material.

Also included in Table 2 are results of tension tests of other S.A.E. X4130 steel tubing that had been heated for 20 min. at 900° C. (1650° F.), oil quenched and then tempered for 1 hr. at 450° C. after welding. These specimens had an average tensile strength of 177,000 to

Fig. 3—Photomicrograph of a Pressure Weld in S.A.E. X4130 Tubing in the As-Welded Condition. × 100

The original interface extended vertically through the center of the area shown. The grains have recrystallized across the interface in a random manner.

182,100 psi. The few specimens that fractured at or near the weld joint had tensile strength values similar to those of the specimens that fractured in the base metal.

Figures 1 and 2 illustrate some typical pressure welds after tension testing. The upset metal, which is quite smooth and symmetrical in contour, had no cracks. Figures 3 and 4 are photomicrographs of the pressure-welded joints in the as-welded and normalized conditions. With a 2% Nital etch, the original interface is not discernible, as crystal growth has occurred across the weld interface.

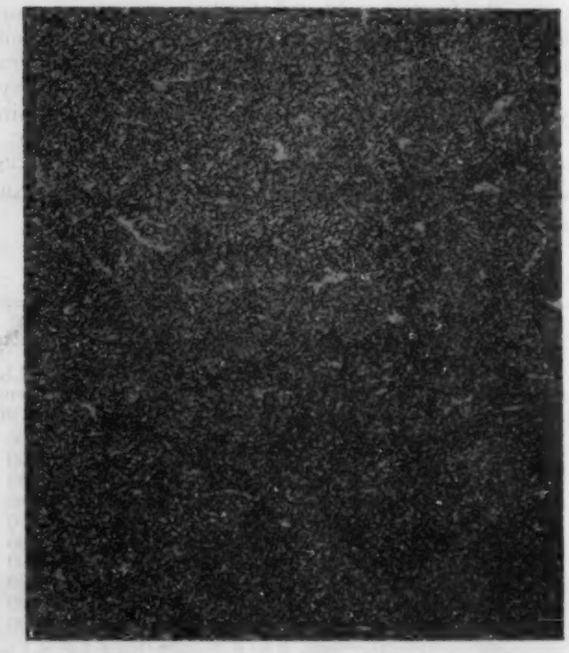


Fig. 4—Photomicrograph of a Pressure Weld in S.A.E. X4130 Tubing After the Tube Was Normalized at 900° C. (1650° F.). × 100

Pressure welds were made in a manganese-molybdenum steel containing 0.28% carbon, 1.60% manganese, 0.22% silicon, 0.04% chromium, 0.43% molybdenum and 0.002% boron. This steel was pressure welded in the form of 1 1/2- x 2-in. bars, at a pressure of 2100 psi. of abutting area, and with a shortening of 7/8 in. These welds had a maximum Rockwell C hardness of 33 at the weld in the as-welded condition, compared with 30 in the as-received base metal. Tension tests of machined 0.505-in. diameter specimens and Charpy impact tests were made of welds in the as-welded and heat-treated conditions. The data listed in Table 3 indicate that the tension-test results were good in the as-welded condition and after an oxyacetylene flame-normalizing treatment at 850° C. These welds fractured 1/2 in. from the weld at approximately 110,000 psi.

In the as-welded condition, the bend-test results were good with specimens bending as illustrated in Fig. 5, with 16% elongation in a 1-in. gage length across the weld. Also shown in this photograph is a tension test specimen, 0.505 in. in diameter by 6-in. gage length, after it had been tested in the as-welded condition. Fracture had occurred 1/2 in. from the weld line. Figures

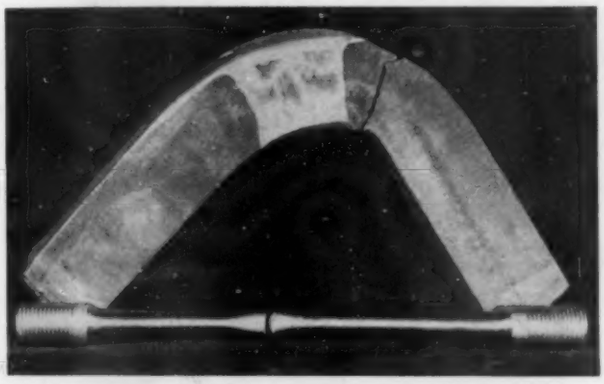


Fig. 5—Photograph Illustrating the Degree of Bend Withstood by a Pressure Weld in 1 1/2- x 2-In., 0.28% C, 1.60% Mn Steel in the As-Welded Condition Before Failure Outside of the Weld

Also shown is an 0.505-in. specimen having a 6-in. long reduced section machined from a welded bar in the as-welded condition.

6 and 7 are photomicrographs at the welds in the as-welded and normalized conditions, respectively, illustrating the grain refinement that was obtained in the weld zone by normalizing at 850° C. Figure 8 is a photomicrograph of the same normalized fine-grained structure at a magnification of 1000 ×, illustrating the heterogeneous structure of ferrite, martensite, bainite and residual austenite that had partially transformed to martensite. Welds with this microstructure, either as-welded or oxyacetylene flame normalized had Charpy impact values of 8.6 to 11.0 ft.-lb. The pseudomartensitic structure that had large acicular particles of ferrite seemed to account for the low impact resistance in a number of low-alloy steels. To correct this, several welds were heat treated at 850° C., to make them austenitic. They were then oil quenched, and tempered at various temperatures to produce a uniform, fine-grain-size, tempered martensite. Figure 9 illustrates the fine-grained tempered martensite at a magnification of 250 × while Fig. 10 shows the tempered martensite at the weld at 1000 ×. The data listed in Table 4 show that this heat treatment has raised the impact resistance of the pressure welds to a value equivalent to that for the original material. The heat treatment can be done with the same heating head as used for the pressure welding.

Table 3—Results of Tension Tests of Pressure Welds in 0.28% C, 1.60% Mn, 0.43% Mo Steel

Treatment	Lb. per Sq. In. Yield Pt.	Lb. per Sq. In. Ult. Str.	% Elong. in 2 In.	% Elong. in 4 In.	% Red. of Area	Fracture
As-received base metal	113,000	125,000	21.0	...	60.9	...
As-welded	82,800	112,000	15.0	7.4	53.7	Base metal
Welded, and normalized at 850° C.	83,000	110,000	10.8	5.7	31.8	Base metal

Pressure welds made in NE 8740 and NE 8630 steels in the form of 1-in. diameter bars were given various heat treatments and tested to determine the effects of grain size and microstructure on the physical properties of the welds. The NE 8740 steel contained 0.41% carbon, 0.88% manganese, 0.54% chromium, 0.53% nickel and 0.24% molybdenum, while the NE 8630 steel contained 0.31% carbon, 0.80% manganese, 0.52% chromium, 0.49% nickel and 0.20% molybdenum. Listed in Table 5 are results of tension, Charpy impact and Rockwell C hardness tests of the welds in NE 8740 steel. In the as-welded condition, the Charpy impact strength of the pressure welds was low, 8.0 ft.-lb., but the yield points and tensile strengths of the welds were high. When the welds were oil quenched from the pressure-welding temperature (about 1230° C.) and tempered for 1 hr. at 650° C., the impact resistance was still low. The physical properties of welds cooled by compressed air immediately after welding and tempered for 1 hr. at 650° C. were not improved noticeably. However, when the pressure welds were reheated for 1 hr. at 850° C., oil quenched and then tempered for 1 hr. at 650° C., a good Charpy impact value of 25 ft.-lb. was obtained. The coarse grain caused by heating the weld zone to a temperature of 1230° C. during the pressure-welding operation had to be refined by reheating to a temperature of 850° C. to make it austenitic, and then cooling rapidly to produce a martensitic structure that could be subsequently tempered in order to obtain good impact resistance. When welds were heated to 850° C. for 1 hr., cooled by compressed air, and then tempered for 1 hr. at 650° C., the Charpy impact strength was 23.0 ft.-lb.

A practical short-time heat treatment that could be used for improving the physical properties of the weld zone in the field was developed. In this method, the weld zone was heated to 900° C. with the welding flame, quenched by compressed air from an annular nozzle and then drawn at a temperature of 650° C. for 3 min., using the oxyacetylene flame for heating. The welds

Table 4—Charpy Impact Tests of Pressure Welds in 0.28% C, 1.60% Mn, 0.43% Mo Steel Notched at Weld Interface

Heat Treatment	Charpy Impact, Ft.-Lb.
Base metal	31.0
As-welded	8.6
Welded and flame normalized	11.0
Welded and oil quenched, and tempered 1 1/2 hr. at 575° C.	33.0
Welded and oil quenched, and tempered 1 1/2 hr. at 600° C.	36.5
Welded and oil quenched, and tempered 1 1/2 hr. at 625° C.	39.1
Welded and oil quenched, and tempered 1 1/2 hr. at 650° C.	42.0
Welded and oil quenched, and tempered 1 1/2 hr. at 675° C.	44.0

thus heat treated had good Charpy impact resistance and tension strength. The Charpy impact resistance was 18.8 ft.-lb., while the average yield point of the welds was 78,000 psi., with an average ultimate strength of 111,000 psi. The microstructure of the welds heat treated in this manner consisted mainly of fine-grained tempered martensite, with some bainite and ferrite. A structure consisting mainly of fine-grained tempered martensite was necessary to produce moderately good impact resistance in the NE 8740 type steel.

Numerous tests were made to determine the effect of heat treatment on the physical properties of pressure welds in NE 8630 steel. It was especially desired to determine a heat-treatment procedure that would not require the use of furnaces. The results of these tests are given in Table 6. The Charpy impact strengths of pressure welds in the as-welded condition were 12.5 ft.-lb. and 13.2 ft.-lb. after tempering them for 1 hr. at 650° C. The Charpy value was raised to 20.0 ft.-lb. by quenching the welds from the welding temperature with compressed air, and then tempering them for 1 hr. at 650° C. When the pressure welds were reheated for 1 hr. at 850° C., then cooled at rates varying from an air-cool to an oil-quench, and then tempered for 1 hr, at 650° C., the

Fig. 6—Photomicrograph at Interface of Pressure Weld in 0.28% C, 1.60% Mn Steel in the As-Welded Condition. Low Impact Resistance. × 100

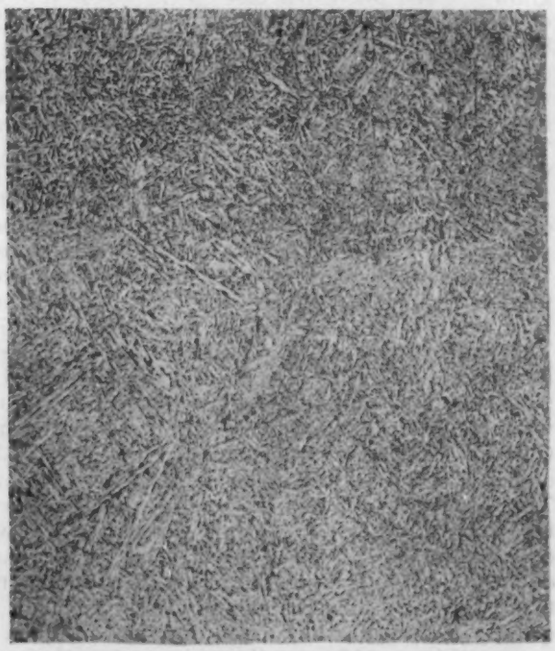
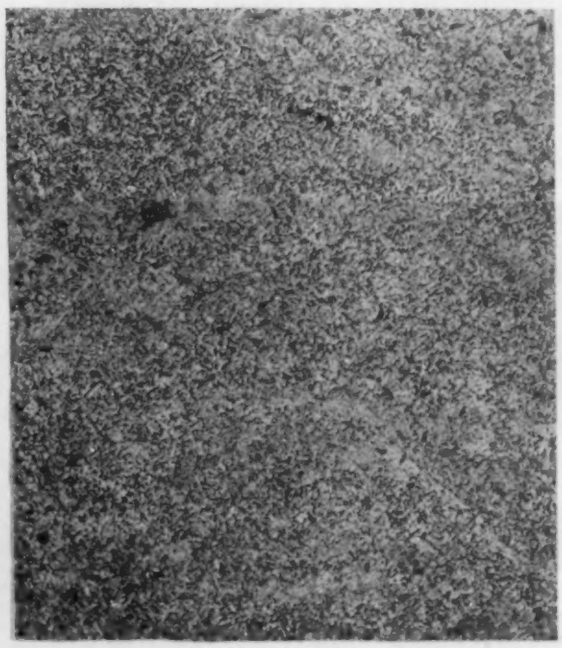


Fig. 7—Pressure Weld in 0.28% C, 1.60% Mn Steel After Normalizing at 850° C. Low Impact Resistance. × 100



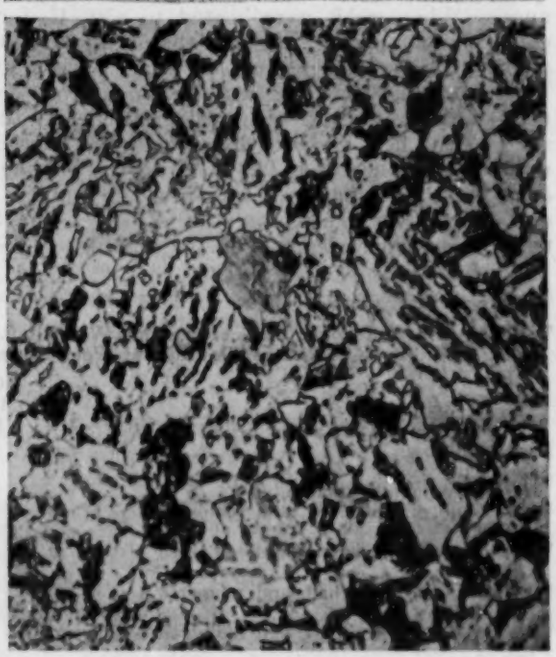


Fig. 8—Same as Fig. 7 but at 1000 ×, Illustrating the Heterogeneous Microstructure Having Low Impact Resistance

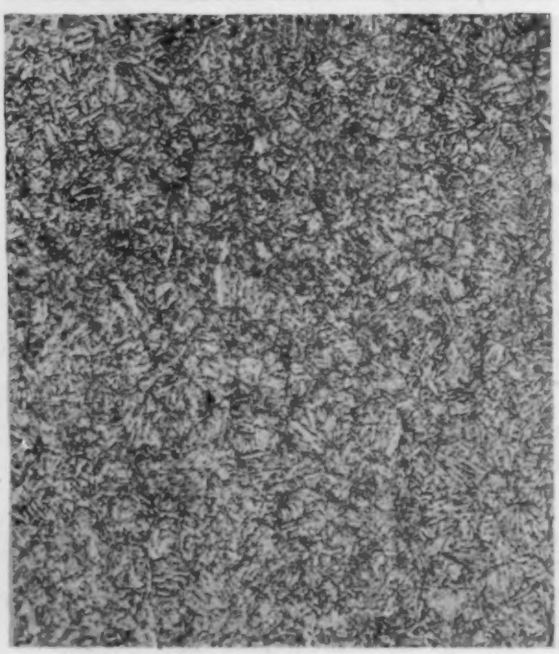


Fig. 9—Pressure Weld in 0.28% C, 1.60% Mn Steel. Oil Quenched from 850° C. and Tempered at 625° C. Good Impact Resistance. × 250

Table 5—Results of Mechanical Tests of Pressure Welds in NE 8740 Steel

	Lb. per Sq. In. Yield Pt.	Ult. Str.	Charpy Impact, Ft.-Lb.	Rockwell C Hardness
As-received base metal	97,500	107,500	18.1	28.0
As-welded	86,000	125,000	8.0	28.9
Oil quenched after welding, and tempered 1 hr. at 650° C.	101,500	123,700	8.0	30.5
Air cooled after welding, and tempered 1 hr. at 650° C.	80,000	109,000	10.7	22.5
Reheated to 850° C., oil quenched, and tempered 1 hr. at 650° C.	117,500	133,500*	25.1	29.0
Reheated to 850° C., cooled by compressed air and tempered 1 hr. at 650° C.	83,000	111,000	23.0	20.0
Reheated by blowpipe to 900° C., cooled by compressed air and drawn at 650° C. for 3 min.	84,000	120,000	18.8	26.4

* All tension-test specimens failed in the base metal except after this heat treatment.

Charpy impact strength was improved considerably. The oil-quenched and tempered welds had a Charpy impact value of 30.5 ft.-lb., with a tensile strength of 103,000 psi. When these specimens were cooled at slower rates by compressed air or in still air, the tensile strength decreased and the Charpy impact resistance increased.

A localized flame heat treatment for this steel was also used that consisted of reheating the weld zone to 900° C. with the use of the welding flame, cooling by compressed air, and then drawing at 650° C. for 3 min. These welds had a Charpy impact resistance of 24.4 ft.-lb. and a tensile strength of 102,750 psi.

An investigation was also made to determine the physical properties of pressure welds in NE 8620 steel in the as-welded condition and after short-time flame treatments. The NE 8620 steel that was used contained 0.16% carbon, 0.75% manganese, 0.56% chromium, 0.56% nickel and 0.16% molybdenum. These welds were made in 1-in. diameter bars at a pressure of 2500 psi. and $^5/_8$ in. shortening at 1250° C. Tension, impact and hardness tests were made. The results of these tests are listed in Table 7.

In the as-welded condition, the pressure welds had an average Charpy impact resistance of 25.8 ft.-lb., a yield strength of 62,750 psi. at 0.5% offset, and a tensile strength of 88,250 psi. Former experience has shown that the ductility and impact resistance of the welds after water or oil quenching could be improved considerably with a consequent lowering of yield and tensile strength by drawing for 2 to 3 min, using the oxyacetylene blowpipe for heating. The necessary drawing time would depend upon the desired mechanical properties of the steel. A good combination of Charpy impact resistance (36.4 ft.-lb.), yield strength (68,400 psi.) and tensile strength (87,670 psi) was obtained by cooling the welds directly from the welding temperature with compressed air and then by drawing them at 650° C. for 1 min. Further improvement in the Charpy impact resistance was obtained by reheating with the oxyacetylene flame to 900° C., followed by cooling at various rates, and then by tempering. With the refined austenitic grain size produced in the steel by these heat treatments, a Charpy impact resistance of 45.0 ft.-lb. was obtained. A metallographic examination was made to correlate the microstructure of the steel with the physical properties of the weld. Figure 11 illustrates the microstructure of a weld in the as-welded condition. The constituents were mainly ferrite and fine pearlite. The average Charpy impact resistance was 25.8 ft.-lb. at a Rockwell C hardness of 17. Figure 12 illustrates a relatively fine-grained ferrite and pearlite microstructure that was produced by reheating to 900° C., followed by compressed air quenching, and drawing at 650° C. using the oxyacetylene flame for heating. The average Charpy im-

Table 6—Results of Mechanical Tests of Pressure Welds in NE 8630 Steel

Condition	Lb. per Sq. In. Yield Pt.	Ult. Str.	Charpy Impact, Ft.-Lb.	Rockwell C Hardness
As-received base metal	41,500	92,750	20.1	20.0
As-welded	59,750	102,500	12.5	21.2
Cooled by compressed air, tempered 1 hr. at 650° C.	73,500	96,250	20.0	16.2
Cooled in still air, tempered 1 hr. at 650° C.	66,000	89,500	13.2	14.5
Cooled in still air, reheated 1 hr. at 850° C., oil quenched and tempered 1 hr. at 650° C.	80,750	103,000*	30.5	16.6
Cooled in still air, reheated 1 hr. at 850° C., cooled by compressed air and tempered 1 hr. at 650° C.	74,000	96,000*	31.0	13.2
Cooled in still air, reheated 1 hr. at 850° C., cooled in still air and tempered 1 hr. at 650° C.	65,200	86,600	42.5	3.5
Cooled by compressed air, reheated by blowpipe to 900° C., cooled by compressed air and drawn at 650° C. for 3 min. with blowpipe	74,000	102,750	24.4	16.3

* These specimens fractured near weld interface after necking down.

Table 7—Results of Mechanical Tests of Pressure Welds in NE 8620 Steel

Condition	Lb. per Sq. In. Yield Strength at 0.5% Offset	Ult. Str.	Charpy Impact, Ft.-Lb.	Rockwell C Hardness
As-received base metal	60,000	85,200	38.0	15.0
As-welded	62,750	88,250	25.8	16.9
Water quenched after welding and flame drawn*	99,250	110,250†	16.1	20.8
Oil quenched after welding and flame drawn	89,000	102,500	23.8	19.4
Cooled by compressed air after welding and flame drawn	68,400	87,670†	36.4	13.8
Water quenched after welding, heated by blowpipe to 900° C., water quenched and flame drawn	87,200	103,000	35.6	19.3
Oil quenched after welding, heated by blowpipe to 900° C., oil quenched and flame drawn	83,400	101,000	30.0	15.0
Cooled by compressed air after welding, heated to 900° C., cooled by compressed air and flame drawn	68,000	88,300	45.0	10.4

* Drawn for 1 min. at 650° C., using oxyacetylene flame for heating.

† Fractured at joint after necking down.

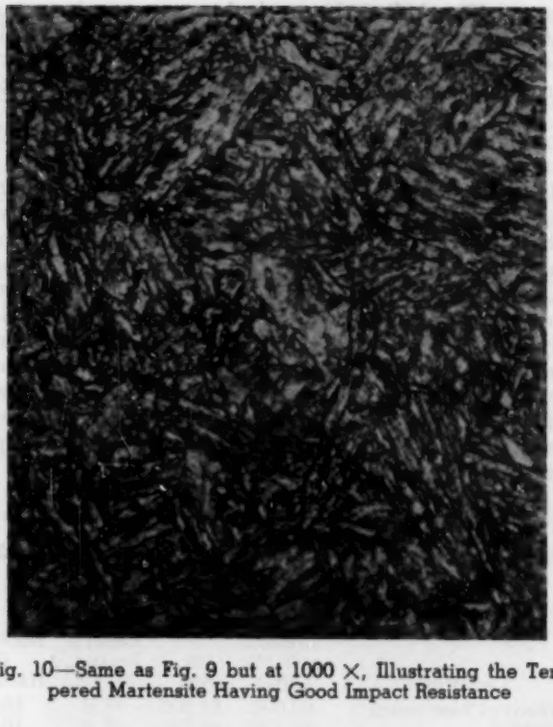


Fig. 10—Same as Fig. 9 but at 1000 ×, Illustrating the Tempered Martensite Having Good Impact Resistance

pact resistance after this heat treatment was 45.0 ft.-lb. at a Rockwell C hardness of 8.

On the basis of these tests, pressure welds in NE 8620 steel have high physical properties suitable for many engineering applications.

An investigation was made on the pressure welding of 5% chromium-molybdenum seamless pipe of $4^1/_2$-in. O.D. by $^1/_2$-in. wall. This steel contained 0.13% carbon 0.40% manganese, 0.34% silicon, 4.68% chromium, 0.26% nickel and 0.50% molybdenum. When this steel pipe was pressure welded, an upsetting pressure of 2500 psi. and a shortening of $^3/_8$ in. was used. This steel had a martensitic microstructure in the as-welded condition, and therefore was hard and of low impact resistance.

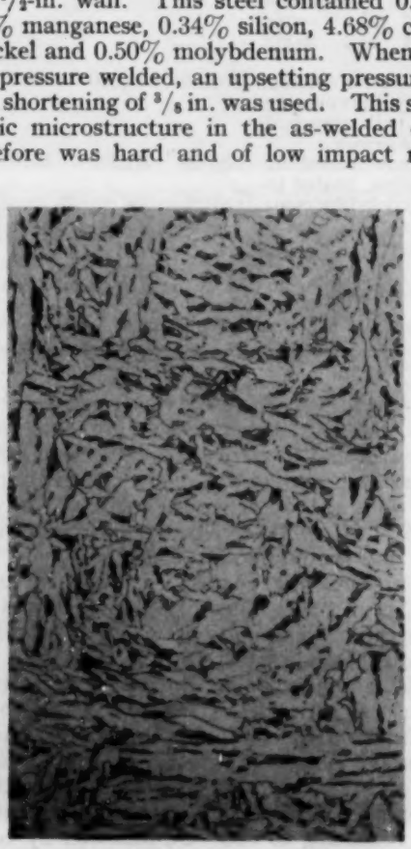


Fig. 11—Pressure Weld in NE 8620 Steel in the As-Welded Condition. × 500

The welds were then heat treated to produce a fine austenitic grain size and a microstructure consisting of ferrite and spheroidized carbides. To do this, the welds were heated to 1010° C., air cooled, reheated to 870° C. and furnace cooled to 730° C. at 11° C. per hour. These welds had a tensile strength of 76,450 psi., with fracture occurring outside of the weld zone, compared with the as-received base-metal strength of 72,000 psi. The endurance limit of these welds determined on the Krouse fatigue-testing machine for 10,000,000 cycles of stress reversal was 45,000 psi., or 59.0% of the weld tensile strength. Other welds were given a shorter heat treatment consisting of heating for 2 hr. at 750° C., followed by air cooling. This treatment also could be accomplished by induction-heating equipment, such as is used at present when carbon-molybdenum steel pipe is welded for steam power plant installations. This heat treatment produced a microstructure consisting of carbide particles and ferrite that gave the steel good toughness and soft-

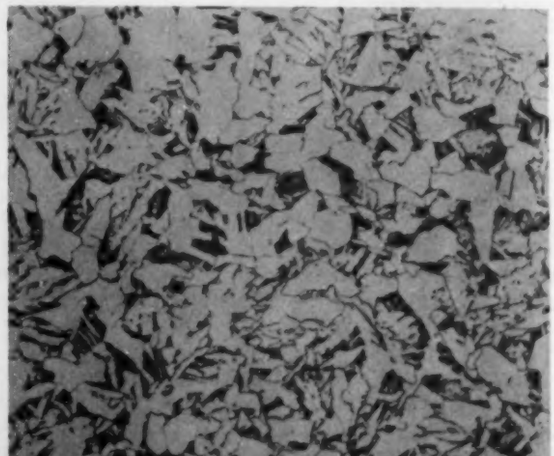


Fig. 12—Pressure Weld in NE 8620 Steel. Compressed Air Quenched After Welding, Heated to 900° C. for 1 Min. with Blowpipe. × 500

ness. These welds had an average tensile strength of 76,600 psi., with fracture occurring in the base metal. Bend test specimens bent flat in both the reverse- and face-bend tests, with the weld reinforcement removed or left on.

A silicon-carbon type of spring steel containing 0.92% carbon, 0.45% manganese and 0.41% silicon was pressure welded in a $^3/_8$- x $2^1/_2$-in. section at a pressure of 2400 psi., with $^3/_{16}$-in. shortening. The Rockwell C hardness through the weld and heat-affected zone ranged from 38 to 41, which was quite uniform. Since the spring steel would have to be heat treated after welding to have uniform physical properties, with high yield strength, across the weld zone, all tests of the welds were made after a standard heat treatment. This consisted of heating at 850° C. for $^1/_2$ hr., oil quenching to 100° C., then air cooling to room temperature, followed by tempering for 1 hr. at 525° C. Test specimens were subjected to a bend test after the weld reinforcement had been removed. After a 40° angle of bend, the specimens failed, with a fine-grained crystalline fracture in the base metal, approximately $^1/_4$ to $^1/_2$ in. from the weld interface.

Table 8—Results of Mechanical Tests of Pressure Welds in 5% Cr, 0.50% Mo Steel

	Lb. per Sq. In. Yield Pt.	Ult. Str.	% Elong. in $1^1/_2$ In.	% Red. of Area	Krouse Endurance Limit, Psi.
	Special Anneal				
Base metal	49,000	72,000	36.0	72.0	...
Pressure welds	39,170	76,450	27.5	56.6	45,000
	750° C. for 2 Hr.				
Pressure welds	31,300	76,600	8.5	...	...

Several 0.250-in. diameter tension-test specimens taken from the base metal and across the weld were tested. The results are listed in Table 9. The average yield point and tensile strength of the pressure welds were 125,000 and 180,600 psi., respectively, in the heat-treated condition, although these specimens failed at the weld. The endurance limit as indicated by the Krouse fatigue test was 91,000 psi., or 50.4% of the tensile strength of the welded steel.

Nonferrous Alloys

Various nonferrous alloys have been pressure welded. The upsetting pressures, which depended on the high-temperature properties of the materials, were determined by experiment. In some cases it was necessary to use high upsetting pressures because of the higher strength of some alloys at elevated temperatures. Some of the copper- and nickel-base alloys were hot-short, and therefore higher than normal pressures were used in order to accomplish the welding at temperatures below the hot-short range.

One interesting application of pressure welding was the joining of a nonferrous alloy containing 80% nickel and 20% chromium to a special austenitic steel containing chromium, nickel, tungsten and 0.50% carbon. These alloys were pressure welded in the form of 3-in diameter bars, at an upsetting pressure of 4700 psi The mechanical properties of the welds were good, as the results below indicate.

Lb. per Sq. In. Y. P.	Ult. Str.	% Elong. in $1^1/_2$ In.	% Red. of Area	Angle of Bend in Free-Bend Test	Krouse Endurance Limit, Psi.
37,600	98,000	31.3	37.5	160	51,000

The tension-test specimens fractured in the Nichrome base metal at 98,000 psi., which is within the tensile-strength range of 95,000 to 100,000 psi. frequently specified for the 80% nickel, 20% chromium alloy. Figure 13 is a photograph of one of these pressure welds made between a disk of the nickel-chromium alloy and a bar of the austenitic steel.

An investigation was carried out on the pressure welding of $^7/_8$- x $1^1/_4$-in. hot-rolled Monel bars. It was necessary to use a high upsetting pressure of 6600 psi. in order to upset the weld zone at a temperature below the hot-short range. When an upsetting pressure much below 6600 psi. was used, severe hot cracks were formed,

Table 9—Results of Tension Tests of Pressure Welds in 0.92% C, 0.41% Si Steel

	Lb. per Sq. In. Yield Pt.	Ult. Str.	% Elong. in 1 In.	% Red. of Area	Krouse Endurance Limit, Psi.
Heat-treated base metal	126,100	190,800	11.3	19.1	...
Heat-treated pressure welds	125,000	180,600	3.0	4.7	91,000

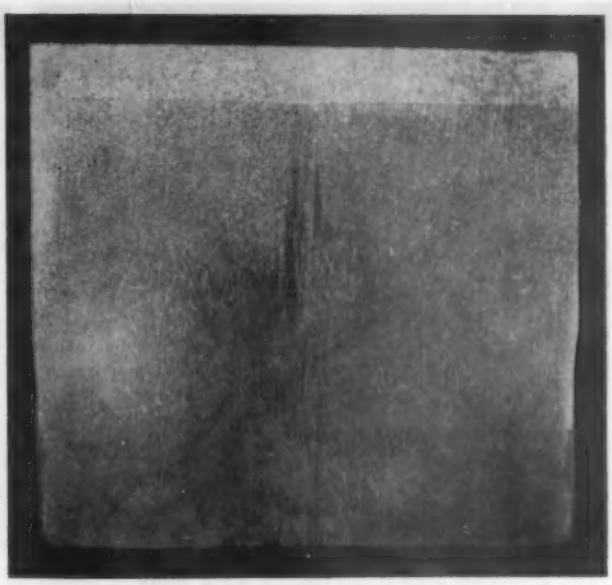


Fig. 13—Pressure Weld Made Between a Disk of Nichrome (80% Ni–20% Cr) and a 3-In. Diameter Bar of Austenitic Valve Steel. Natural Size

Table 10—Tension Tests of Pressure-Welded High-Aluminum, High-Iron Bronzes

	Lb. per Sq. In. Yield Pt.	Ult. Str.	% Elong. in 2 In.	% Red. of Area	Fracture
	Grade A-3				
Base metal	43,500	95,300	25.0	32.5	...
Welds	35,000	88,100	14.7	21.5	At joint
	Grade 15				
Base metal	52,500	99,900	29.0	41.3	...
Welds	40,375	95,750	20.0	26.3	Base metal
	Grade 18				
Base metal	64,000	109,000	17.0	13.4	...
Welds	48,000	89,725	17.0	16.3	At joint
	Grade 45				
Base metal	86,000	116,800	11.0	16.3	...
Welds	65 750	105,000	7.0	10.2	Base metal

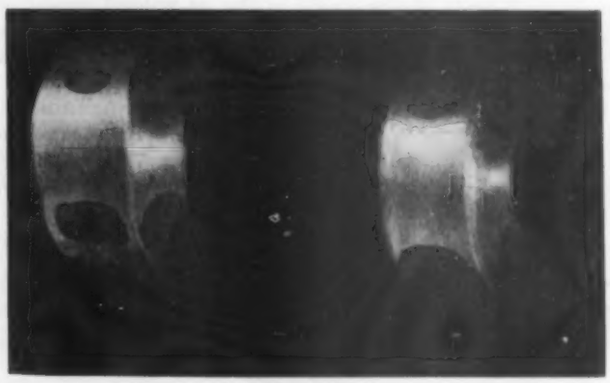


Fig. 14—Pressure Welds Made in Monel at 6600 Psi. Upsetting Pressure. The Specimens, with Weld Reinforcement Removed, Were Bent 180° Without Failure

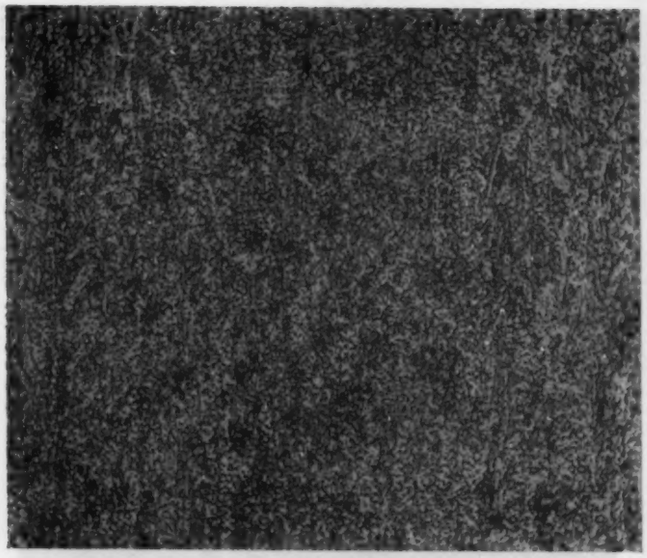


Fig. 15—Weld Zone of a Pressure Weld Made in Grade 45 High-Aluminum, High-Iron Bronze. × 75

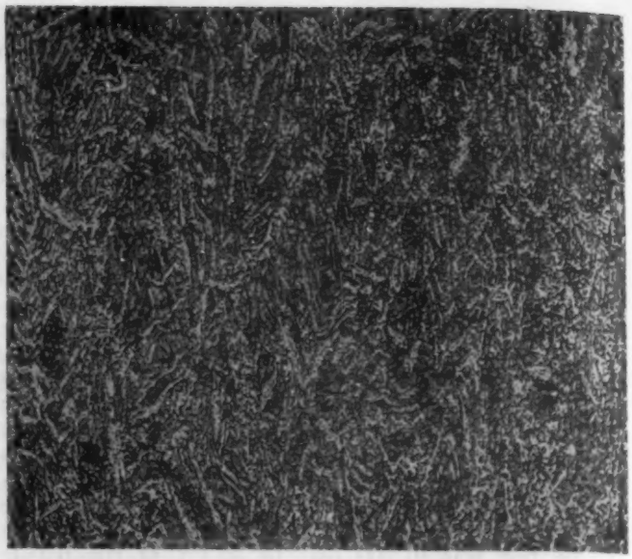


Fig. 16—Base Metal Located 1/8 In. Away from Weld Zone Illustrated in Fig. 15. × 75

but with a pressure of 6600 psi., the cracks were superficial and were eliminated when the weld reinforcement was removed. Figure 14 illustrates the good quality of pressure welds made at 6600 psi. These specimens with upset removed bent 180° without failure.

One-inch diameter Everdur bars having flat abutting faces were pressure welded with good results at an upsetting pressure of 7500 psi. and a shortening of 1 in. The ultimate strength of the pressure-welded Everdur bars was 56,000 psi., compared with a value of 52,000 psi. for this alloy in the soft condition, and a value of 70,000 psi. in the cold-worked condition. When pressure welds were made in Everdur at an upsetting pressure much less than 7500 lb psi., hot cracks developed in the weld zone.

An investigation was made to determine the possibility of pressure welding high-aluminum, high-iron bronzes. Pressure welds were made in 1-in. diameter bars of 4 different grades, the chemical compositions of which are listed below.

	Chemical Composition				
Grade	% Al	% Fe	% Ni	% Mn	% Cu
A-3	9.5	1.25	...	...	Balance
15	9.5	3.4	...	...	Balance
18	10.8	3.5	...	...	Balance
45	10.3	3.0	5.0	1.0	Balance

All 4 grades were pressure welded satisfactorily at upsetting pressures of 2000 to 2250 psi. and 1-in. shortening. High ultimate-strength values were obtained in tension tests of the welds in the as-welded condition. Welds in the A-3 bronze had an ultimate strength of 88,100 psi., while the values for grades 15, 18 and 45 were 95,750, 89,725 and 105,400 psi., respectively. The detailed tension-test results are listed in Table 10. Figure 15 illustrates the fine-grained microstructure at the weld in Alloy 45, while Fig. 16 illustrates the coarse-grained base-metal microstructure adjacent to a weld made in the same alloy.

Pressure welds in Tobin bronze, an alloy of 60% copper, 39% zinc and 1% tin, had a tensile strength of 63,000 psi. as-welded, which was practically the same as the average base-metal tensile strength of 60,000 psi. specified.

Summary

Pressure welds in low-alloy high-strength steels such as NE 8740, NE 8630, manganese-molybdenum and carbon-silicon spring steel of high-carbon content, had high tensile strengths in the as-welded condition, but a quench and temper heat treatment were required to secure high Charpy impact resistance in the welds. The lower-carbon steel, NE 8620, had a tensile strength on the same order as the unwelded steel, accompanied by good ductility and impact properties in the as-welded condition. However, the impact resistance of the welds can be improved to still higher values by heat treatment.

Pressure-welded S.A.E. X4130 steel tubing had practically the same mechanical properties as did the unwelded steel.

Steel containing 5% chromium, 0.50% molybdenum was pressure welded successfully, although annealing was necessary to restore optimum ductility in the weld zone, just as it is necessary after welding by other processes.

Nichrome required a relatively high upsetting pressure during the welding, because of its good high-temperature mechanical properties, as compared with steel. In order to pressure weld both Monel and Everdur, a high pressure was required to upset the weld zone below the hot-short range of temperature, in order to prevent hot cracking. Welds in these materials had excellent mechanical properties.

Tobin bronze and high-aluminum, high-iron bronzes were pressure welded successfully, with the welds having high tensile strength and good ductility.

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The Development of High-Strength Welding Quality Alloy Steels and Their Postwar Applications*

By Howard Miller†

THE early period of the war production effort found the entire welding industry in a veritable research rat race for information and practical knowledge of the welding materials and processes involved in welding armor plate and armor castings. The main reason for the lack of precise knowledge of these materials and processes was that no practical commercial demand for such high strength in weldable material had been experienced prior to the outbreak of the war in Europe. Faint indications of what might be required came from the evidence in regard to tanks and mobile artillery used by the Germans and Italians in the Spanish war, but industrial America was "not interested." However, even if we have worked up the necessary knowledge as to materials and processes prior to the European outbreak, the shortages of critical alloys which occurred would have made much of the work on the welding of the nickel and other "rich" type alloys useless, except as it might have given us more knowledge of the basic principles involved. These alloy shortages caused considerable changing and revamping in materials and practices, such that the specifications at the war's end showed considerable change from the early and mid-period war standards. Much of this change was a gain in knowledge and application of commercially cheaper materials.

To be specific, actual specifications for welding quality steel plates with yield points from 70,000 psi. up to 120,000 psi. have been drawn up and can be met with commercially produced materials and welded with fairly low cost welding rods and technique. We say, "commercially produced," meaning that such steels are capable of quantity production rather than that they can compete on a commercial basis with lower grades of steel in any or all applications.

The extent to which these high-strength and relatively higher priced materials can be utilized will devolve on two main conditions in the postwar world.

The first, and governing condition of course will be that the material in its application is *in the end* the least expensive to buy and maintain. The second condition is that for certain parts or applications, a high-strength material in welded design is the only possible way of obtaining the desired results.

In the first case, a lower strength, lower cost material may be used but the service life may be short with a high replacement cost or the heavier weight of lower strength materials may result in higher operating costs, as in the case of transportation equipment.

In the second case come such conditions as where size limitations of a part require extra high-strength materials or the working stresses due to design may be beyond the strength of the ordinary or low-alloy steels.

One other condition may also be found and that is where ordinary service stresses are low enough to be covered by common or low-alloy steels, but, under certain abnormal conditions, much higher stresses may occur that would be dangerous to human life or to costly equipment. To design in normal strength materials to take care of the possible abnormal overloads might entail the construction of a part considerably overweight and in the case of transportation equipment, a costly overburden to provide safety in case of abnormal service conditions such as collisions between trains or derailments.

One of the most interesting quantity commercial applications of a war-developed, high-strength welding quality steel is now found in the end underframing of some of our high-speed streamlined railroad passenger cars.

To begin with a discussion of the steel—The Ordnance Department, in order to make a truly mobile gun out of the World War I, 155-mm. 50-caliber rifled gun, redesigned the carriage so that the barrel and recoil could be left on the carriage and moved around without having to dismount the barrel for transportation. This involved changing from riveted to welded construction, eliminating several large castings in upper and under carriage and application of pneumatic instead of solid rubber tires and finally reducing the weight of the carriage from ten tons to seven tons. The first experimental carriages built with 50,000 psi. yield point steel definitely showed that either higher yield point steel or thicker and heavier sections would be required in order to stand up under the heavy shock of firing the gun which was capable of throwing a 95-lb. shell up to a 15-mile range.

It was decided to try for a 70,000-psi. yield point material and several standard alloys were tried out but, owing to the hardening in the weld characteristics of all of these steels, no really satisfactory material was developed until the carbon contents were reduced and Ferrite strengthening alloys were used. The steel conforming to the following range was very successfully applied and many parts of the specification as finally used were based on properties that were characteristic of this type:

Carbon, 0.16 max.; manganese, 0.60–0.90; sulfur and potash, 0.04 max.; nickel, 1.30–1.60; copper, 0.90–1.10; molybdenum, 0.20–0.30; semi-killed or silicon killed. Aluminum treated for grain size.

Physical properties after stress relieving 4 hr. at 1100° F., 70,000 min. yield strength; 135,000 max. tensile.

Weld bead hardness not to exceed 300 Vickers Brinell under test conditions.

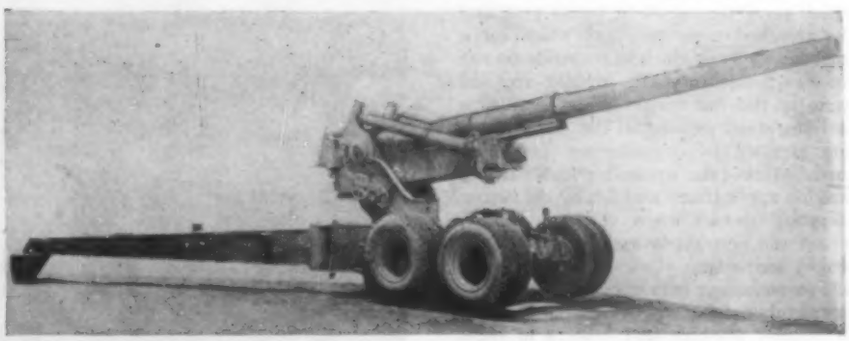

Fig. 1—Carriage, Gun, 155-Mm., M1. Firing Position Right Front, 15° Elevation

* Scheduled for Twenty-Seventh Annual Meeting, A.W.S., Atlantic City, N. J., week of Nov. 17, 1946.

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Fig. 2—Carriage, Gun, 155-Mm., M1. Elevating Mechanism

Nick-break test on stress-relieved material must show tough gray fracture.

The last condition involving the nick-break test was added to insure the notch toughness of the steel in the finished condition because it was found that some gun carriages which met all other specifications as to weld hardness, ductility in elongation, etc., had broken badly in cold weather and that steels from these parts all showed a crystalline, brittle-type fracture, while steels that stood up properly, in cold weather especially, showed the tough gray fracture in the nick-break test.

The photos show the gun carrage that used this 70,000 minimum psi. yield strength steel.

At the close of the war the railroads began placing orders for new passenger cars for replacement of their old heavyweight equipment. A replacement program involving around 7000 to 8000 new cars over the next three to four years is going forward at the present time. Practically all of the new equipment on order is lightweight design. A small percentage is being built of aluminum, but the balance is either stainless steel throughout or a combination of stainless exterior covering sheets with low-alloy structural framing or of all low-alloy steel painted exterior design.

The end sections of the center sill which carry the couplers, buffer gear and the attached cross members which carry the center plates which in turn ride on the truck bolsters, are the highest stressed parts in the car under riding conditions and also must sustain all the end on buffing stresses in coupling up trains in yards, slack take up and release during braking applications and finally the heavy bumping shocks when collision, derailments and emergency applications of the brakes are made. Originally the center sills on passenger cars were made continuous members from end to end, but damage to coupler pockets and buffers in hard bumping and also to the bolster and center plates in derailments presented

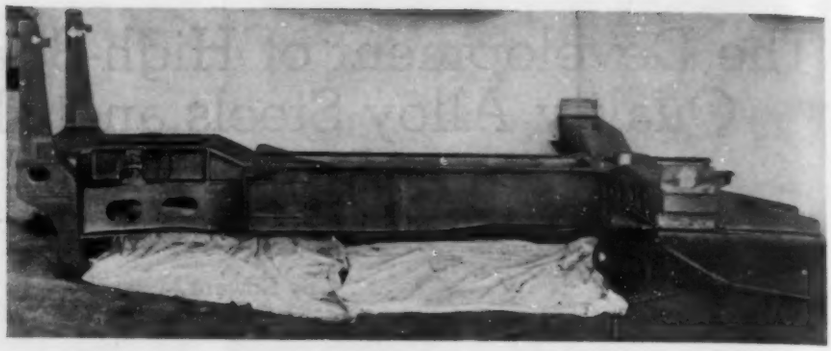

Fig. 3—Side View of End Underframe

considerable difficulty in repairs. Newer designs involved the making up of separate members for these end parts of the underframe and riveting or welding these subassemblies to the center sills, just back of the bolsters. Some of these subassemblies are made as a one-piece casting, including the cross bolsters. Others have a cast central unit with draft gear pockets, and the bolsters are riveted or welded to the center sill section of the casting. The most generally accepted design is a single weldment containing the end sill, buffing gear, pockets, draft gear pockets, cross bolster and center plates with wings for the dummy or false end sill and step attachment.

When cars collide forcibly and the floor of one happens to be a little higher than the other, this higher floor and underframe may climb up over the end framing of the lower car, shear off the vertical end posts and plow through the car, telescoping the car and causing considerable damage. To prevent such telescoping action some designers apply an extra strong collision post or shear member at each side of the door frame and incorporated in the vestibule door posts.

The Interstate Commerce Commission sets up certain minimum strength values for the draft sill and end sill construction with a specified minimum compression strength at a certain distance above the center line of the coupler. All builders exceed these minimum values as a matter of good judgment. Common practice generally shows 25% over the design minimum.

However, cars built today will still be in operation 20 or 25 years from now if past records are maintained. Present speeds run up to spurts of up to 110 to 120 mph. with long stretches of 90 mph. speed. In all probability average speeds on railroad trains may increase 20 or 25 mph. during the next ten years as steam turbine and electric drives become more in general use and further progress is made in train signals and controls. As the total energy in a mass in motion increases as the square of the velocity in feet per second, the impact resistance of the coach structures at higher speeds must be still higher than present designs if we are to have safe operation at these increased speeds.

The prewar draft sill and bolster construction was based on 50,000 yield point, low-alloy steel welded construction or cast steel of similar strength. By changes in design and substituting a 65,000–70,000 yield strength material the crushing strength of this weldment has been increased to such an extent that with no increase in weight the safety factor of 75 to 100% over the I.C.C. minimum is

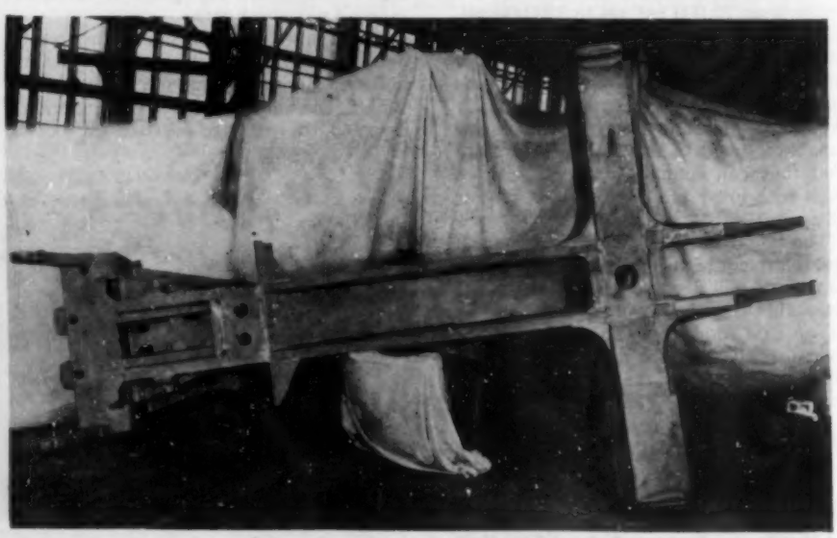

Fig. 4—Top View of End Underframe

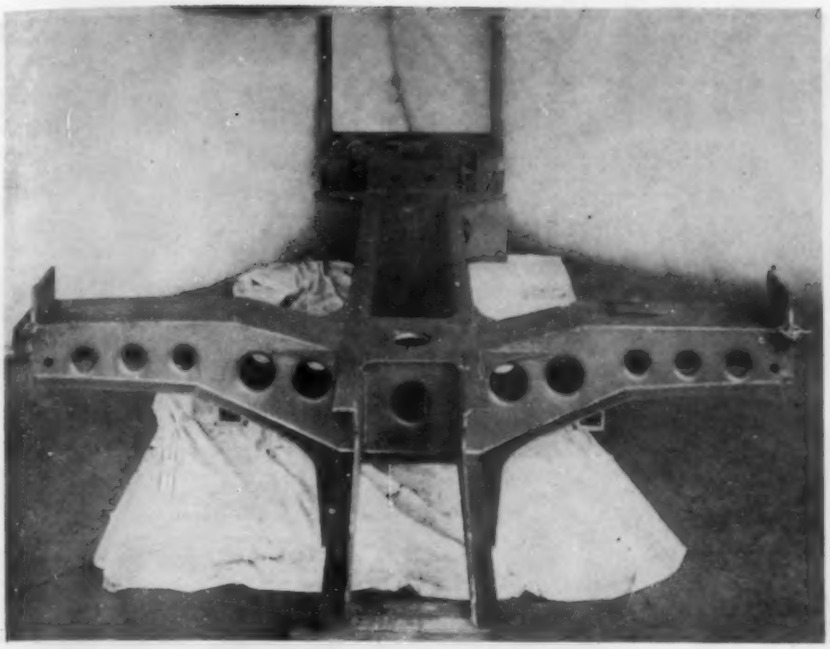

Fig. 5—End Underframe Looking Toward End Door Opening

being met. The nickel copper moly steel plates are furnished in the as-rolled condition and pickled to remove scale for cold-forming operations. Certain parts such as side rails and the insetting of the plate around the lightening holes in the bolster side plates are cold formed at room temperatures. The various parts are made up in subassemblies with all welds full scarfed and 100% penetration required in fillet as well as butt welds. Weld metal for butt welds is required to meet full strength of the plate in tension. Weld metal in fillets is held to lower strength due to shape in design of the fillet welds. All assembly is done in rotating positioners and the finally completed weldment is then stress relieved for around 2 to 4 hr. at 1100° F. and furnace cooled.

The requirements as to alignment and prevention of warpage are very strict as this full assembly must fit accurately into the center and side sills of the car and must lie true and flat in a plane about 10½ ft. wide by 16 ft. long. The finished weldment is placed on a flat bed of this size and several points in the structure, notably side bearings and center plate, must be in true position as measured from the flat plate surface.

Several gusset plates are used in corners in order to prevent stress concentrations at points where longitudinal members and cross members meet in a plane. Often in welded construction this X marks the spot at which failures begin. In addition to applying gusset plates in these corners we do not try to run up to an end with the weld rod but we make the corner of the gusset wider at the end and finsh out a complete butt weld between the gusset plate and the flange edge or panel and then a clean sharp torch cut is made to form a smooth tangent into the curve of the gusset plate and the flame-cut edge is hand ground on the edges and a smooth flowing stress surface is the result of this practice, without any notching effect at the end of a weld bead. The same welding practice as was used in welding gun carriages is applied in these underframes and the welding is the same high quality through and will pass magnaflux or X-ray testing when so required.

The welding rods used are 100% mineral coated type with sufficient moly in the coating to develop the proper strength in the weld metal when a small per cent of alloy parent metal is fused in the weld. The weld-hardening properties of this analysis are very low and bend tests on as-welded, as well as stress relieved, specimens show very good ductility in the welded zone.

The impact resistance of this steel at low temperature is very important and the following charts show the effect of temperature down to −50° F. on the steel used in this type of weldment.

In conclusion on this application, we have here a well-balanced design which is purposely designed well above today's minimum requirements in order that it may not be found wanting when future conditions demand higher strength than now required.

In attempting to gather more information regarding the possibilities of commercial applications of these higher strength welding quality steels we prepared a questionnaire which was mailed to the engineers of about 40 large manufacturers of welded equipment covering several fields of applications such as cranes and mill machinery, excavating and dirt moving equipment, large presses, Diesel engines and locomotives and other such applications. The questionnaire asked if they were giving consideration to these materials and what would be any advantages or disadvantages in their application.

The response to the questionnaire was very disappointing as to the number of replies and also as to the information given which was almost entirely negative as to any advantage in design and more so in regards to the price disadvantage.

In designs requiring rigidity the modulus of elasticity of the material is the governing factor and the higher strength steels offer no advantage in this regard. Extra strength above minimum requirements can be obtained with slightly thicker sections of low-cost common steel as in presses, shears and punches.

Diesel locomotives develop so much horsepower with regard to their total weight that in some cases extra heavy bed plates are used in order to obtain enough weight on drivers to obtain the proper traction for the horsepower developed.

Diesels for ships might show some advantage in weight savings with high-strength welded frames and bases, but probably the Navy would be the only field of interest at present as present ship costs are very high and the saving in weight cost might be out of line with the benefit of extra cargo capacity earned.

It begins to look as if the immense amount of work done on this type of steel and its welding will have very little if any effect on our present or future commercial applications with the exception of the passenger car underframe.

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Field Erected Pressure Vessels*

By Fred L. Plummer†

DURING the past few years failures of large, field-erected pressure vessels have been very rare. However, those failures which have occurred have been so dramatic as to cause engineers responsible for the design, fabrication and construction of such vessels, to re-examine the many variable factors which may contribute to the safe and economical service performance of a given vessel, or may result in another spectacular failure.

The following discussion will, in general, be limited to welded, field-erected pressure vessels constructed of steel conforming to A.S.T.M. Spec. A-10 or A-70, and designed to operate at or near atmospheric temperatures. Applicable codes in current use do not require any variation in design procedure or selection of materials for vessels operating in the range of temperature from −20 to 650° F. The steels noted above have been generally used in the construction of large, field-welded pressure vessels and are, of course, approved for such use by the codes governing such construction.

Properties of Steel

The specifications which cover the manufacture of these steels, A-10 and A-70, require that the steels be made in an open hearth or electric furnace; limit the amount of sulphur and phosphorus, and in some cases the amount of carbon, copper and manganese; specify the range of tensile strength, yield point and elongation as determined by a standardized test on a standard test specimen; provide for certain bending properties and, in the case of firebox quality of A-70 steel, for a homogeneity test. These physical properties of the *test specimen* are determined at *room temperature* by a given test routine which, in general, results in the creation, at a definite rate, of pure tension or compression stresses acting only in the direction parallel to the longitudinal axis of the small test specimen. There are no requirements in the specifications as to whether the steel be "rimmed," "killed" or "semikilled," nor as to whether silicon, aluminum or some other element is to be used if the steel is "killed." The specifications place no restrictions on the rolling procedure used in producing the plates from ingots nor the varying of the carbon content for plates of different thickness.

The physical properties as determined for the test specimen provide a proper basis for the comparison of the performance of different steels under the test conditions. Experience with thousands of steel plate structures over a period of many years indicates that these same test results have provided a satisfactory, if perhaps not fully adequate, basis for selection of working stresses which were used in the design of safe and reasonably economical structures of medium size, operating under conditions which did not vary too widely from those of the test.

During the past several years, the use of new and larger capacity industrial processes has resulted in an ever-increasing demand for pressure vessels of greater size and unusual shapes, designed to operate at higher pressures while subject to a wider range of temperatures. In the plates of such tanks, stress distribution is not simple, yielding at low temperatures of areas near discontinuities may be essential, and load may be applied very rapidly as by a "shock." These conditions vary widely from those used in determining physical properties by the standard test. Failures may indicate that the manufacture of steels, which are to be fully satisfactory for this type of service, must be more carefully controlled and that additional test requirements must be met.

Design and Fabrication

Design procedures as outlined in governing codes, in general, require the determination of primary membrane stresses in vessel walls and heads. Plate thicknesses for cylindrical and spherical shells are determined by these stresses, using a safe working stress equal to one-fourth to one-fifth the specified minimum ultimate tensile strength of the steel as determined by the standard test, and welded joint efficiencies of from 75 to 95%. Plate thicknesses for dished heads, flat heads, braced and stayed surfaces are determined by semiempirical formulas using more conservative safe working stresses. The codes provide very little guidance in the determination of stresses in areas at and near the points where supports are

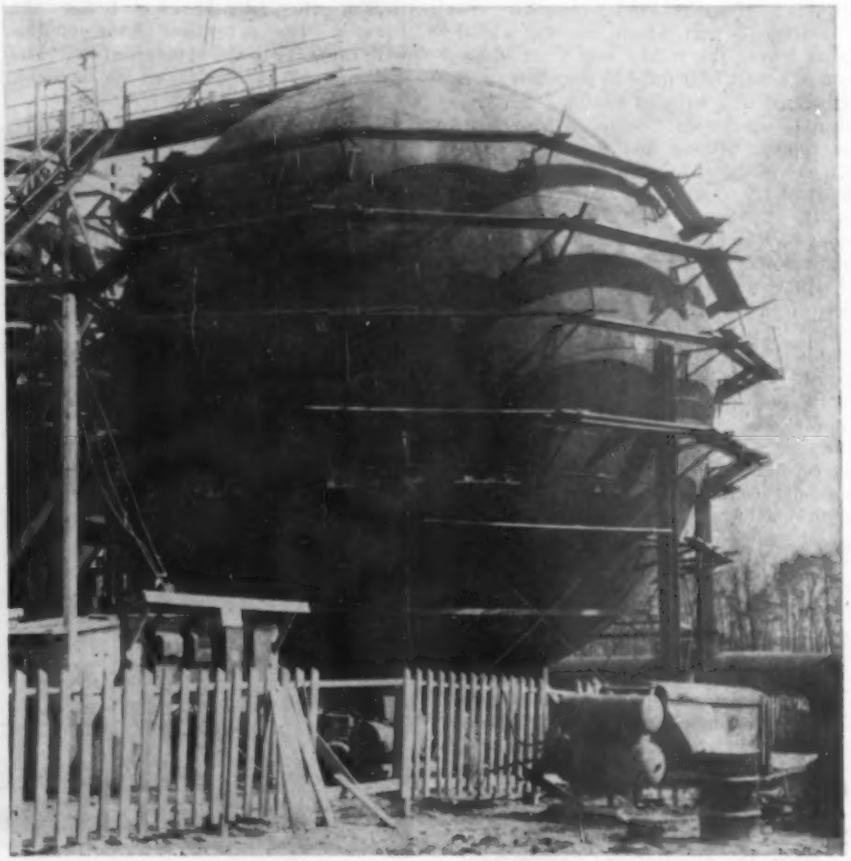

Fig. 1—Rupture of Sphere During Hammer Test

* Scheduled for Twenty-Seventh Annual Meeting, A.W.S., Atlantic City, N. J., week of Nov. 17, 1946.

† Director of Engineering, Hammond Iron Works, Warren, Pa.

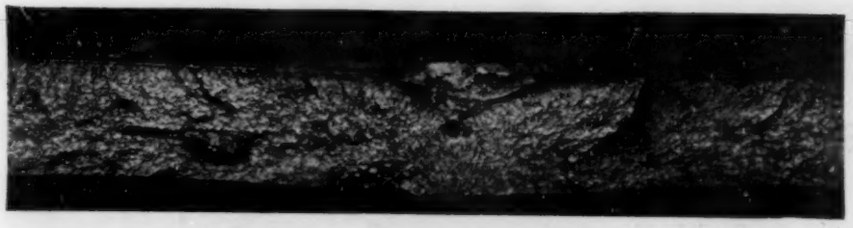

Fig. 2—Torn Plate at Origin of Rupture

attached to large vessels or at points where discontinuity stresses are caused by abrupt changes in thickness, shape or curvature, including those which occur at the junction of cylindrical shells and heads of various shapes. The results of a theoretical analysis of the stresses at such points may be of little value in predicting the actual stresses which will exist under service operating conditions, since the theoretical stresses are normally determined by assuming that all deformations are elastic. Actually local yielding of the plate material during test, or later, may result in minor changes in shape which result in stresses quite different from those indicated by such a theoretical analysis. Many engineers have completed such an analysis for the test of a relatively simple vessel and found predicted discontinuity stresses in excess of the specified strength of the plate material. Yet the vessel safely withstood the test and many years of subsequent service with no visible sign of distress. Failures, though rare, indicate the need for more definite information as to how much such relief we can count on and under what operating conditions and for what kinds of metals.

During the period from the time a steel plate leaves the rolling mill until it becomes a part of a finished structure, it is subjected to a series of handling and fabricating operations. Some of these, such as rolling, dishing and flanging, create stresses in the plate in excess of the elastic limit of the material in order to permanently change its shape. Other operations such as punching, burning, shearing, planing and welding cause local failure of the plate material. Some operations are performed on plates at elevated temperatures; however, rolling and dishing of plates are usually done at room temperatures. This is a necessary and normal fabrication procedure, approved by all codes. The A.S.M.E. Code for Unfired Pressure Vessels requires that cold forming be done by pressure and not by blows. It would seem logical, therefore, to permit additional forming of plates in a completed vessel under test, provided such forming is desirable from a stress relief standpoint and the resultant change in shape of the vessel does not detract from the usefulness of the vessel for its intended purpose. Thus a hydrostatic test of a completed vessel, resulting in local yielding at certain points of discontinuity, might be considered a final fabrication procedure, leaving a vessel in which subsequent operating stresses would not exceed conservative working values.

As a result of these fabricating operations, including the welding of the final assembly, the physical and metallurgical properties of a plate or of part of a plate in the completed vessel may be appreciably different from those of the same plate as determined when it left the rolling mill. We need additional information as to the magnitude of these differences and their significance.

Failure of Hydrogen Storage Sphere

During February 1943 one of three spheres used for storing hydrogen at the Schenectady, N. Y., plant of the General Electric Company failed with explosive violence. This sphere, having a diameter of 38 ft. 6 in., was designed and constructed for a working pressure of 50 psi., in accordance with the A.S.M.E. Code for Unfired Pressure Vessels, following the rules of paragraph U-69. The shell thickness of 0.66 in. was determined by using a welded joint efficiency of 80% and a working stress of 11,000 psi. equal to one-fifth the 55,000 psi. minimum ultimate tensile strength specified for the A.S.T.M. A-70 steel which was used. Since the sphere was not designed to contain liquid, it was supported by light angle columns attached to the sphere at points about one-twelfth the circumference below the equator. The center lines of the columns were tangents to the sphere surface. The sphere was tested with air at 62.5 psi. pressure and had been in service more than 3 months at the time of the failure. There was no loss of life; however, several persons located in an adjacent building were injured.

The failure took place at about 2:45 P.M. on Feb. 16, 1943, at which time the air temperature at the site was about 9° F. During the preceding day and night the temperature had been approximately −23° F. At the time of the failure, the pressure in the sphere was about 52 psi.

The plates forming the sphere were joined with about 800 ft. of butt-welded seams. When the failure took place, the shell was broken into over 20 pieces separated by about 630 ft. of tear. Of this total less than 2 ft. followed welded seams or the adjacent strip of "heat affected" metal. Obviously then, the welding, which was of normal commercial quality, was not an important source of weakness. Note also "that the fractures did not involve, except in a minor way, the support leg attachments." Thus it does not seem possible that stresses in the shell near the column attachments contributed in any way to the failure.

The report of the investigating committee, from which the above quotation is taken, indicates that the failure probably originated in the sheared inside edge of a 20-in. diameter manhole neck where small cracks had been created by the cold rolling of the $^{7}/_{8}$-in. thick plate to this small diameter and welding it into the shell and reinforcing plates. The report lists 5 separate factors, which "separately would not have seemed serious, combined to cause failure." The factors[1] are listed as (1) residual stresses in the manhole neck, (2) low-notch impact strength of the steel at the low temperature, (3) stress concentrations due to the manhole open-

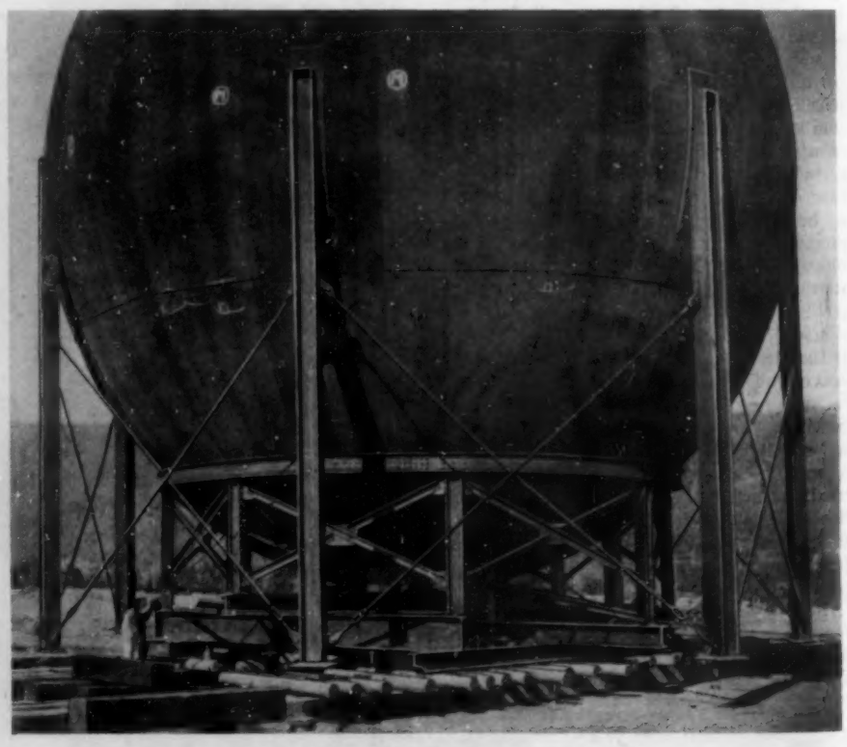

Fig. 3—Moving Spherical Pressure Vessel

ing (4) stresses above normal due to rising temperature and gas pressure at 52.5 psi , (5) shock, probably as a result of the sudden extension of an incipient crack in the manhole neck.

A great many manholes of identical construction have given excellent service over long periods under substantially the same operating conditions. We cannot avoid stress concentrations around openings, the possibility of shock loads or of the occurrence of occasional stresses slightly higher than those corresponding to the design loads. It is possible to eliminate initial cracks in the neck and to at least reduce residual stress values. It may be possible to economically improve the low temperature impact strength of the steel if we can determine what controls are essential.

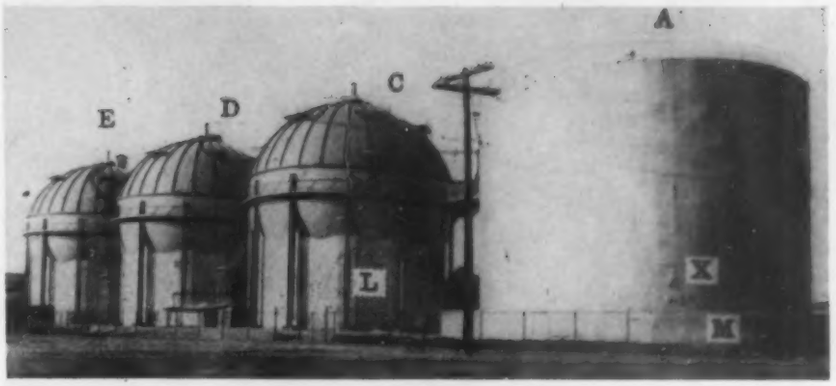

Fig. 4—Low-Temperature Storage Vessels

Partial Failure of Sphere During Test

Late in March 1943 at an Ordnance Plant in Pennsylvania, one of two spheres designed to store anhydrous ammonia weighing about 42 lb. per cubic foot at a temperature of 40° F. and a pressure of 75 psi., ruptured while being subjected to a hammer test. These spheres, having a diameter of 40 ft. and a shell thickness of approximately 7/8 in., were designed and constructed in accordance with the same rules and with the same working stresses and weld joint efficiency as those used for the sphere described above. A.S.T.M. A-70 steel, flange quality, secured from two sources, was used in constructing the spheres. The plates from one source were rolled from "rimmed" steel, whereas those from the second source were rolled from "semikilled" steel. Since these spheres were designed to contain a liquid, each was supported by 7 vertical columns, equally spaced around the periphery, and welded to steel reinforcing pads at the vessel's equator. These columns consisted of sections of 10-in., 89-lb., wide flange beams and the reinforcing pads were 3/4 in. thick plates, 19 in. wide by 84 in. long.

The first of the two vessels, identical in size and construction, had been subjected to the hammer test called for by the 1940 edition of the A.S.M.E. Code for Unfired Pressure Vessels (this requirement has now been eliminated by revision of the code) while filled with water and subjected to a hydrostatic pressure of about 115 psi. It had then been subjected to a hydrostatic pressue of 150 psi. and had been approved for service by the inspection authorities. Construction of the second vessel had been completed and it had been filled with water having a temperature of about 40° F. The hydrostatic pressure had been increased to about 115 psi. and the hammer test had been nearly completed when the rupture shown in Fig. 1 suddenly occurred as the direct result of a blow struck with an 8-lb. sledge on the first vertical seam to the left of the middle column. Starting at the point where the blow was struck, a horizontal tear extended left and right to the adjacent column attachment pads, with some secondary tears around the left-hand column in Fig. 1, probably resulting from the deformations which were caused by the release of pressure and the weight of the contained water. Practically none of the tears followed welded seams, the principal tear extending across two plates and parts of the two adjacent plates approximated at right angles to the vertical seams joining these plates.

Following the failure some 20% of the total lengths of welds in the vessel were subjected to magnaflux examination. No serious defects were detected and the welding which had been done under adverse winter weather conditions was found to be of good commercial quality. A complete strain gage survey of the first vessel empty, full of water without additional pressure, and full of water with raised pressures of 40 and 75 psi. was made and the indicated stress intensities were computed. These values indicated the general adequacy of the design and did not disclose any critical stress intensities in the areas adjacent to the column attachment pads, even though the water test load was about one and one half times as great as the design load. The manholes of these spheres were of the saddle type and therefore not subject to defects of the type held partially responsible for the failure of the hydrogen storage sphere.

Again, it seems obvious that neither the welding nor the column attachments constituted serious sources of weakness. Manhole construction could not be blamed in this case. The failure was initiated by a hammer blow which struck on a vertical welded seam where there was a slight overlap of weld metal producing a notch effect combined with a small weld porosity in the interior of the seam. If there had been no hammer test or if the blow which caused the failure had been struck at a point an inch or more distant from the point where it was struck, it seems quite possible that the failure would not have occurred. The relatively low temperature of the plates, about 40° F. when the failure occurred, again raises the question of their impact strength. The seam where the tear started joined two plates, one having been supplied by each of the two sources noted above. Tests on coupons cut from these two plates indicated that the impact resistance of the plate material was more than cut in half by reduction of the test temperature from 78 to 40° F. Thus, it would seem that the factors contributing to this failure were (1) a shock load, (2) low impact strength of the steel plate, (3) stress concentration due to minor weld defects and (4) possibly residual stresses. Figure 2 shows an edge view of the torn plates near the point at which the tear started.

Four plates including the attached columns were cut from the structure and replaced by new plates and columns. The vessel was then retested and approved for service. Later because of plant changes it was decided to move the two spheres to a different location. Figure 3 shows the repaired sphere being moved. It was again tested after being relocated and has given trouble-free service since that time.

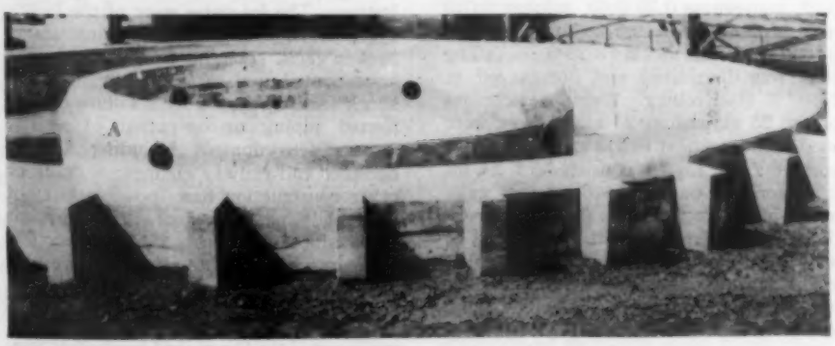

Fig. 5—Foundation for Cylindrical Toro-Segmental Tank

Failure of Sphere in Special Test

Following the first failure described herein, a number of spheres which had been in service for some time were inspected to determine if similar defects existed in the manhole construction. Usually any unfinished edges of the fittings

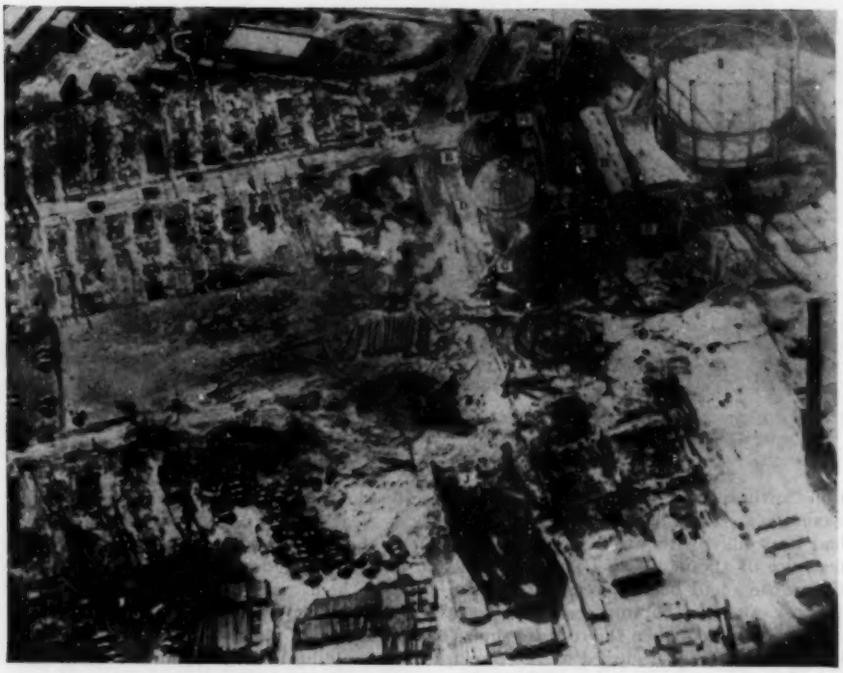

Fig. 6—Demolished Area After Fire

were chipped and ground smooth and the weld seams were examined by the magnaflux method. If defects were discovered, these were repaired or new manholes were installed. Among others, six spheres located at an ordnance plant at Morgantown, W. Va., were so inspected and repaired. These spheres, which were 38 ft. in diameter, had been in service for two years. They had been designed to contain a liquid weighing 42 lb. per cubic foot and for a gas pressure of 50 psi., using an allowable stress of 11,000 psi. and a weld joint efficiency of 90%. Before being placed in service, these spheres had been subjected to a hydrostatic pressure of 75 psi.

Following repairs to the manholes, it was decided to retest the spheres by filling them with water and increasing the hydrostatic pressure to 100 psi. The first sphere successfully passed this retest. The second sphere was being tested during January 1944 and the hydrostatic test pressure had been raised to 98 psi. when "the bottom tore out and the top fell in on it." The sphere was completely destroyed although there was not, of course, the explosion effect which accompanied the failure of the hydrogen storage sphere. The results of extensive study which followed this failure have not yet been generally released.

A study of the herringbone lines on the torn edges of the plates "indicated that the failure started at a point just below where a column was attached to the shell." There were continuous tears connecting four of the eight column attachments and local tears in the plate near three of the other column attachments. Again practically none of the tears followed the welded seams—about 4 ft. of tear out of a total of 350 ft. There was some 800 ft. of welded seam of generally good quality although some points were found where there was a lack of complete fusion. It should be noted that the columns were supporting a load equal to about one and one half times the design load and that the vessel was subjected to a hydrostatic pressure equal to two times the design pressure. It was probably safe for all normal working conditions. Subsequent strain gage readings made on a duplicate sphere indicated high local stresses at the column attachments. The construction history of this sphere indicated the possibility of high residual stresses caused by difficulties in fitting the columns and equator course.

Failure of Low-Pressure Storage Vessel at Low Temperature

Figure 4 shows three spheres and one toro-segmental tank with cylindrical shell, which were designed and used for the storage of liquefied natural gas at a temperature of −250° F. and a pressure of less than 5 psi. The 3 spherical containers, completed in January 1941, consisted of an outer shell of standard carbon steel, 3-ft. thick cork insulation and an inner storage sphere, 57 ft. in diameter, constructed of a nickel steel, meeting the following chemical analysis: carbon 0.08–0.12, manganese 0.30–0.60, sulphur 0.045 max., phosphorus 0.045 max., silicon 0.10–0.20 and nickel 3.25–3.75. The steel was deoxidized and normalized at 1550° F. after rolling. Welding electrodes of the 25 chromium–20 nickel type were used with a preheat to 212° F. The skirts market *L* in Fig. 4 consisted of 2.5-in. thick concrete-on-metal-lath curtain walls on 12-in. thick footing walls built sometime after the spheres had been placed in service, to confine any small leaks which might develop. The cork-filled space between the spheres was kept vapor tight and continuously ventilated by dry, low-pressure gas discharged through a top vent to the atmosphere. Each container was supported by 12 columns attached to the outer shell at its equator. The spheres were designed to contain a liquid weighing 26 lb. per cubic foot and for a vapor pressure of 10 psi., using a working stress of 13,750 psi.

The vessel marked *A* in Fig. 4* consisted of an inner cylindrical shell of the same nickel steel, 70 ft. in diameter and 42 ft. high with toro-segmental bottom and roof, 3-ft. thick rock wool insulation, and an outer cylindrical shell of standard carbon steel, 76 ft. in diameter and 51 ft. high with toro-segmental bottom and cone roof. The roof of the outer shell and the bottom of the inner shell were carried on Douglas Fir wood columns. The roof of the inner shell was supported by 24 steel columns fabricated from the nickel steel plate. The reinforced concrete foundations for the complete unit are shown in Fig. 5. This vessel was completed, tested half full of water and with an air pressure of 5 psi., and placed in service during 1943. A crack developed in the bottom of the tank when the liquid gas was first introduced. However, this was repaired and greater care used to insure a uniform drop in temperature over the tank bottom when the liquid gas was again allowed to enter the tank.

On Oct. 20, 1944, at about 2:40 P.M., an employee saw streams of liquid or fog issuing from this tank at the points marked *X* in Fig. 4. There was a rumble, clouds of vapor, flame and the tank seemed to disintegrate rather than explode, discharging liquefied gas over the plant and into sewers and drains where the liquid gas vaporized, mixed with air and resulted in explosions and fires over a wide area. Figure 6 shows the resulting damage estimated at about $6,800,000. About 128 persons lost their lives and an additional 300 suffered injuries.

Some 20 min. after the initial failure, an explosion signaled the failure of the spherical container marked *C* in Fig. 4. This failure was probably caused by collapse of the supporting columns caused by loss of strength due to heat from the fires which followed the failure of tank *A*. The spherical containers *D* and *E* did not fail and remained full of liquefied gas as shown in Fig. 7, after the fires were extinguished.

The investigating boards were unable to determine the cause of the failure. A study of the fragments of the inner shell of tank *A* indicated that the rupture started at the center of the roof, extended radially outward to the shell, down through the shell and inward through the bottom. The fractures were of the brittle type having many of the characters of broken glass. Possible factors which may have contributed to the failure included: shock loading caused by a failure of connected piping or operation of nearby industrial equipment including a drop hammer and railway engines; a crack or other construction flaw (possible but not probable); use of a steel which may not be satisfactory at such an extremely low temperature even though exhaustive pre-

* Figures 4–7 reprinted from Bureau of Mines Report of Investigation 3867 and from July 1945 Report of Technical Consultants Covering Investigation of the Fire at the Liquefication, Storage and Regasification Plant of The East Ohio Gas Co., Cleveland.

liminary tests had indicated that the steel would be satisfactory; high discontinuity stresses at junction of shell and bottom. There was no evidence of sabotage, a preliminary explosion of a gas-air mixture, any failure of operating personnel or any unusual operation being carried on in the plant area. Filling of the four tanks had been completed and the liquefaction process was being shut down when the failure occurred. The design was considered adequate. The use of dykes having a capacity equal to that of the storage vessels might have prevented most of the deaths, injuries and damage to surrounding property.

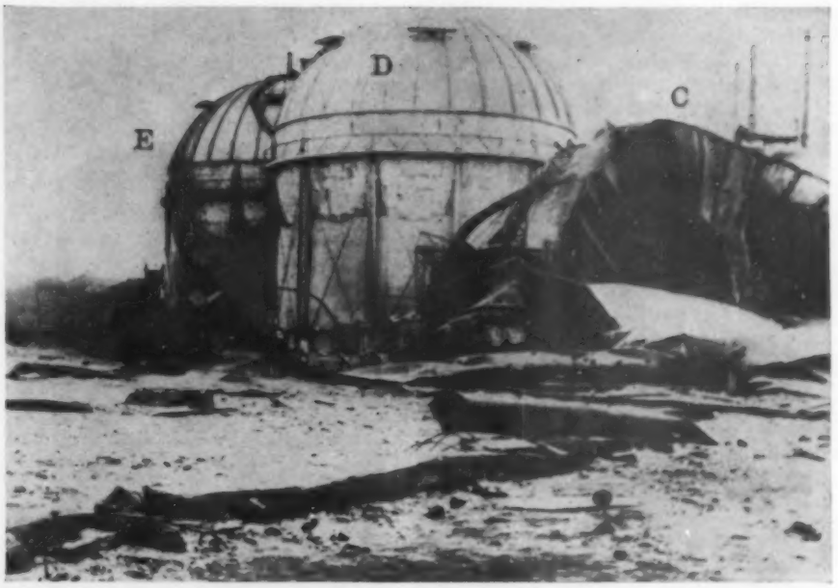

Fig. 7—Spherical Containers After Fire

Lessons from Failures

These are the only important failures which have occurred during recent years including the war period, when expediency sometimes may have called for the acceptance of imperfect materials and workmanship of less than the highest quality. In each case it was impossible to determine a single major defect which caused the failure. The factors which were considered most important in causing the failures were, in general, different in each case. However, considering the failures as a whole several conclusions seem to be justified.

In general, the strength of butt-welded joints is adequate even though the welding is not nearly perfect. No important portion of the tears followed the welded seams in any of the vessels which failed. In the Schenectady sphere, lack of fusion and a crack extending through more than 20% of the plate thickness did not provide sufficient weakness to keep a tear, which followed a seam for a short distance, in the seam. On the other hand a local weld defect may contribute to the initiation of a fracture of the brittle type.

Openings for manholes, nozzles of various types or other purposes, are critical areas and should receive special care in fabrication and erection. An opening cut in a stressed plate necessarily interrupts the uniform distribution of stress and results in stress concentrations. The economical reinforcing of such openings and the introduction of nozzle necks results in abrupt changes in thickness, causing additional complications in the stress distribution. The heavy welding frequently used in such construction must result in both "residual" and "reaction" stresses of relatively high intensities.

When liquid-filled pressure vessels, such as spheres or cylindrical vessels with dished- or cone-shaped heads, are supported by brackets or columns attached to the shell of the vessel, stress distribution in the shell plates, at and near the attachment of such supports, is radically altered. Abrupt changes in plate thicknesses may result in stress concentrations. It is possible to estimate the stress intensities in such areas by analytic methods; however, it is probably not possible to accurately predict the maximum values of the stresses by any analytic method. Hundreds, even thousands, of vessels in service and supported in this manner prove that, in general, such stresses are not critical.

Steels in general and under usual operating conditions have a remarkable capacity for withstanding the destructive effects of superimposed "residual stresses," "reaction stresses," "stress concentrations" and stresses due to applied loads, without excessive yielding or change in form of the given structure. It is generally recognized that this "capacity" depends upon the type and quality of the steel, its previous history, the degree of restraint exerted upon a given portion of the structure, the kinds of stress to which it is submitted, its temperature and other variable factors. In each of the failures reported herein, low temperatures were reported. In each case "residual" and "reaction" stresses might have contributed to the failure. The capacity of steel to withstand shock loads seems to drop severely at low temperature. In one case there was a definite impact load and in each case there might have been some such effect.

Service failures are almost always the results of "brittle" type fractures. The elongations which occur in standard tension and bend tests are not found in service failures. If, in addition to determining the stress conditions which result in the failure of test specimen, we could determine the conditions (stress, temperature, restraint, etc.) which might be expected to result in a service-type failure then we would have made definite progress in our attempt to design economical and safe structures.

Basic Theory of Design

There are several basic theories which may be followed in attempting to determine the safe and economical thickness of the walls in pressure vessels. These include among others: (1) the determination of the maximum principal stress, considering only the tangential stress and disregarding all others; (2) the determination of "true" stress due to the maximum strain from all stresses; (3) the determination of the maximum shear stress and assuming an allowable shear stress equal to one half of the allowable tensile or compressive stress; (4) the determination of the maximum strain energy assuming the same amount of deformation work for failure of the vessel as for the simple tension test; (5) the determination of maximum deformation work, representing the maximum energy less the work performed in changing the volume of the material. Boe[3] has presented an interesting comparison of these and other theories, demonstrating the relative conservativeness of each for different design conditions and for both "heavy-" and "thin-" walled vessels. In his conclusions he points out that there is a wide divergence between the different formulas; that methods (1) and (2) are unsafe for the design of heavy-walled vessels; that method (1) may give unsafe values for internal pressure but conservative values for external pressure; that the curve showing the degree of conservativeness may "undergo a reversal of values in going from the thin-walled to the heavy-walled field, the borderline being approximately $t/D = 0.1$ to 0.2" (t/D being the ratio of wall thickness to outside diameter); that in a thin-walled vessel a soft ductile material will be stronger than a harder, more brittle type material; "that a certain volume of metal should do an equal amount of work of confining a certain volume under a given pressure" even though the shape of the container might vary as from a sphere to a cylinder.

The thickness of the walls of pressure vessels of the types discussed in this paper are almost always determined, as previously noted, by computing the tangential membrane stresses. In some cases it may be possible that we over-simplify our design procedure when we do this.

Brittle Failures in Welded Plate Structures

Failures of field-erected, welded pressure vessels have been very rare; however, a relatively large number of failures of welded ships occurred during the recent war period. As a result of these failures, several important research programs were formulated and many investigations have

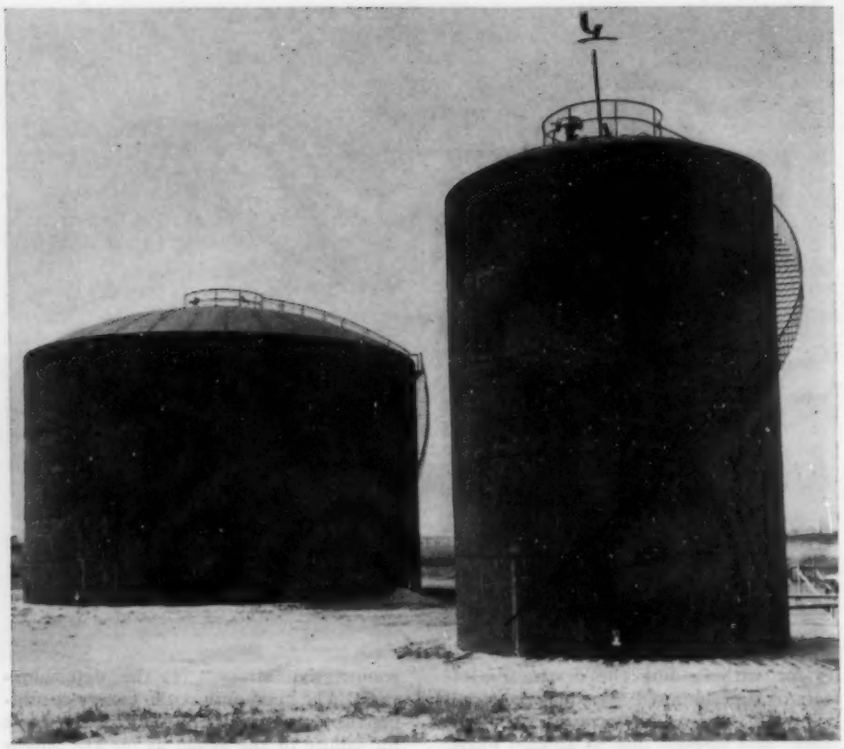

Fig. 8—Low-Pressure Storage Tanks

been completed. A number of excellent papers have been published giving the results of some of these investigations. Many independent studies and investigations have also been reported.

Shepler[3] states that three factors—temperature, speed of loading and constraint—in addition to the material itself, determine its brittleness. Constraint may be spoken of "as transverse stress, triaxiality, geometrically generated internal stress, size effect, notch effect, severity of notch, width or thickness effect and perhaps others." The tests which he reports were made on a number of different steels to locate the transition zone between ductile and brittle failure as each of the three factors noted above was varied. He states in his conclusions that in a butt weld of nonkilled ship plates "the base material 1 in. from the center of the weld is the most brittle, while the deposited metal at the weld center is most ductile and the nonkilled base material 5 in. from the center line is intermediate, being not quite as ductile as the samples of unwelded nonkilled ship plates tested as-received." An increase in constraint resulted in an increase in brittleness for a given speed of loading. The order of ductility for the materials tested agreed with that given by the standard Charpy impact tests.

Grinter[4] has discussed the propagation of cracks in thin plates and has suggested an explanation as to why such cracks exhibit the characteristics of brittle fractures. He demonstrates how triaxial tension stresses of considerable magnitude may exist near the end of a crack as a result of the differences in plate thickness of the material caused by the release of stresses in a direction perpendicular to the crack as the crack progresses and the corresponding increase in stresses acting in the same direction in the material immediately adjacent to the end of the crack.

Kennedy,[5] in his prize winning paper, describes a series of experiments related to the "brittle" failures of welded mild steel structures. He lists the following factors as influencing the cracking of welded steel plates: Temperature, welding stresses, heat treatment after welding, preheating, thickness, mechanical discontinuities, welding voltage, geometry and methods of loading. In his conclusions he states (1) that temperature is the most important factor contributing to brittle fractures of mild steel, (2) that residual stresses play a minor but important role in causing fractures, (3) that reaction stresses can cause a brittle fracture in notched plates if the notch is sharp, (4) that metallurgical changes associated with welding are important factors contributing to brittleness, (5) that the rate of propagation of a crack through ship plate steel may equal about 4000 ft. per second. He recommends the following means of alleviating the danger of brittle fractures in welded mild steel structures: (1) postheating to 1100° F. or higher, (2) preheating to 400° F. or higher at time of welding, (3) use of little overbuild of weld, (4) use of lower welding voltage.

In panels welded into a frame so as to create biaxial reaction stresses, fractures did not occur any easier than in similar panels welded into a frame so as to produce reaction stresses acting in one direction only.

A group of members of the Welding Research Council prepared and edited a comprehensive statement which was published[6] under the title "The Weld Stress Problem." This statement gives a clear definition of "residual" and "reaction" stresses and discusses weldability stress raisers, steel quality, low temperatures, strain aging, rigidity of structure and residual stresses.

Hollomon[6a] has prepared an exhaustive and stimulating report for the Welding Research Council covering the basic problem of fracture and the failure of welded steel structures.

Stress Relieving and Testing

In the past it has been considered impractical to attempt to stress relieve large field-erected pressure vessels. Greene and Holzbaur[7] have described a method of low temperature stress relieving, conceived by H. E. Kennedy, and used during the war at Sun Shipbuilding and Dry Dock Co. This method involves the controlled heating of the plate on each side of the weld seam to a temperature of 350 to 400° F. followed by proper cooling. The heating may be done by two oxyacetylene heads located either side of the welded seam and followed at a proper distance by water or air-water sprays. Normal speed of travel for $^3/_4$-in. thick plates is given as about 16 in. per minute. Extensive test results are given. The authors state in their summary that residual stresses in or adjacent to welded seams generally equal from 40,000 to 50,000 psi. in the longitudinal direction but are usually relatively small and unimportant in the transverse direction. They site the test results and experience with actual boat structures as evidence that "this process offers an effective and practical method of eliminating these residual stresses entirely or reducing them to negligible values without distortion or deformation."

It has been reported[8] that residual stresses, which are not of higher order than biaxial, have no effect on safety, in so far as ordinary mild steel is concerned, and that states of stress, whether residual or due to applied loads, if not higher than biaxial, do not alter appreciably the initiation of plastic flow as compared to the uniaxial tension test.

The A.P.I.-A.S.M.E. Code for Unfired Pressure Vessels permits the use of mechanical peening, as described in the code, as a method of stress relieving vessels assembled in the field.

Welded seams of field-erected pressure vessels have usually been examined visually and by means of specimen cut from the welded seam for examination for soundness. The welds in the completed vessel are usually tested by subjecting the vessel to a hydrostatic or air pressure equal to from 125 to 200% of the design working pressure. Some years ago, the codes which controlled the construction of the majority of such vessels, required that the vessel be hammered while subjected to such overloads. However, this requirement as it applies to most field-erected vessels has been eliminated from these codes.

The welds of a few field-erected pressure vessels have been examined by radiographic methods; however, the cost of such examination is relatively high.

Low-Pressure Storage Vessels

Low-pressure storage vessels may be considered as including those vessels in

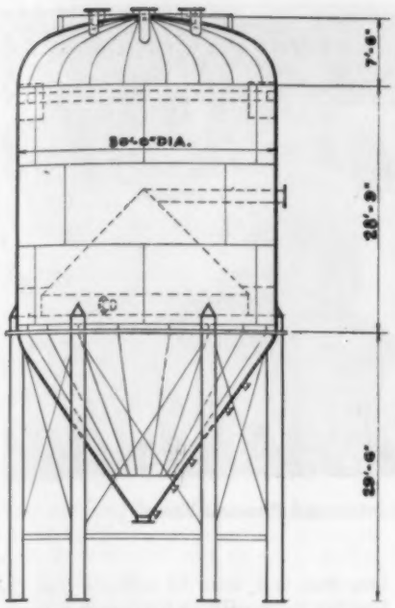

Fig. 9—Typical Low-Pressure Process Vessel

which the vapor pressure, in addition to any liquid pressure, does not exceed 15 psi. and the construction is therefore not covered by the A.S.M.E. or the A.P.I.-A.S.M.E. Codes for Unfired Pressure Vessels. Such vessels usually consist of cylindrical shells with dome-shaped roofs and dished or braced flat bottoms, or of special shape tanks such as "spheroids," "ellipsoids" or "torospheres."

Such vessels are usually constructed of relatively thin plates and are supported directly on the ground. Manhole and nozzle construction also involve the use of relatively light plates and small size welds. Thus some of the factors which may have contributed to the failure of vessels designed for higher pressures and supported on columns, are absent or of less importance in the construction of these vessels.

The design and construction of such low-pressure vessels generally follow the rules of the A.P.I. Codes governing the construction of liquid storage tanks except that more conservative working stresses are normally used. Many such vessels designed for a working pressure of 2.5 psi. are used by the petroleum industry for the storage of volatile gasolines and other petroleum products.

No important service failures of vessels of this type have been reported except that of the cylindrical tank with toro-segmental top and bottom described in this paper. In September 1938 a spheroidal tank of the "noded" type failed while being tested; however, that failure was believed due to faulty workmanship on a joint so located as to be inaccessible for even visual inspection. Later designs were modified so as to eliminate this condition.

Two cylindrical tanks with globe roofs and flat bottoms having storage capacities of 27,500 and 5000 barrels, and designed to withstand a vapor pressure of 2.5 psi. are shown in Fig. 8. A number of similar tanks having storage capacities up to 30,000 barrels have been constructed and placed in service. In these tanks diagonal ties connecting stiffener beams attached to the tank shell and the flat tank bottom are provided to prevent distortion and excessive stresses at the shell to bottom connection when the liquid level is low and a vapor pressure exists in the tank. These ties and stiffener beams are designed for low working stresses and constructed so as to avoid high bending stresses in the tank bottom and shell plates. In general, no analysis or design problems involving important unknown factors are encountered.

Special Purpose Pressure Vessels

A typical process vessel, designed to operate at a pressure of only 20 psi. in addition to hydrostatic pressure, is shown in Fig. 9. This vessel consists of a cylindrical shell with semiellipsoidal head and cone-shaped bottom, supported on six tubular columns. The construction includes an inner inverted cone, launder, baffles, pipes and a larger number of relatively large nozzles located in all parts of the vessel. A platform with operating equipment is located on the top of the tank and access stairs and platforms are attached to the tank. The determination of plate thicknesses and of reinforcing around openings in accordance with code requirements is a routine operation. Only two design problems require special attention. One of these, the design of columns and their attachment to the vessel, will be discussed later. The second problem concerns the construction at the junction of the cone bottom and cylindrical shell. This vessel was designed in accordance with the rules of the A.S.M.E. Code for Unfired Pressure Vessels using the design values for paragraph U-69 construction.

The 1946 Addenda to this code in paragraph U-36m gives rules covering the use of conical heads under internal pressure. Earlier editions of the code did not cover the use of conical heads on pressure vessels. The code rules applied to this vessel require that the conical head must be attached to the cylindrical shell by a knuckle having a radius of not less than 21.6 in. (6% of the maximum head diameter) and a thickness not less than the thickness of the cone. The code rules do not require the use of a compression girder at this intersection. The engineers representing the purchaser requested that a heavy compression ring be furnished for this vessel as shown in Fig. 9. This is one of several design problems for which different engineers are liable to suggest widely different solutions.

Boardman[9] has presented a general solution for this type of connection when no knuckle is provided. Application of his method of analysis provides a logical basis for determining the amount of reinforcing, if any, required for this case.

Lee[10] has also proposed formulas for calculating stresses in the conical bottoms of cylindrical tanks. His derivation indi-

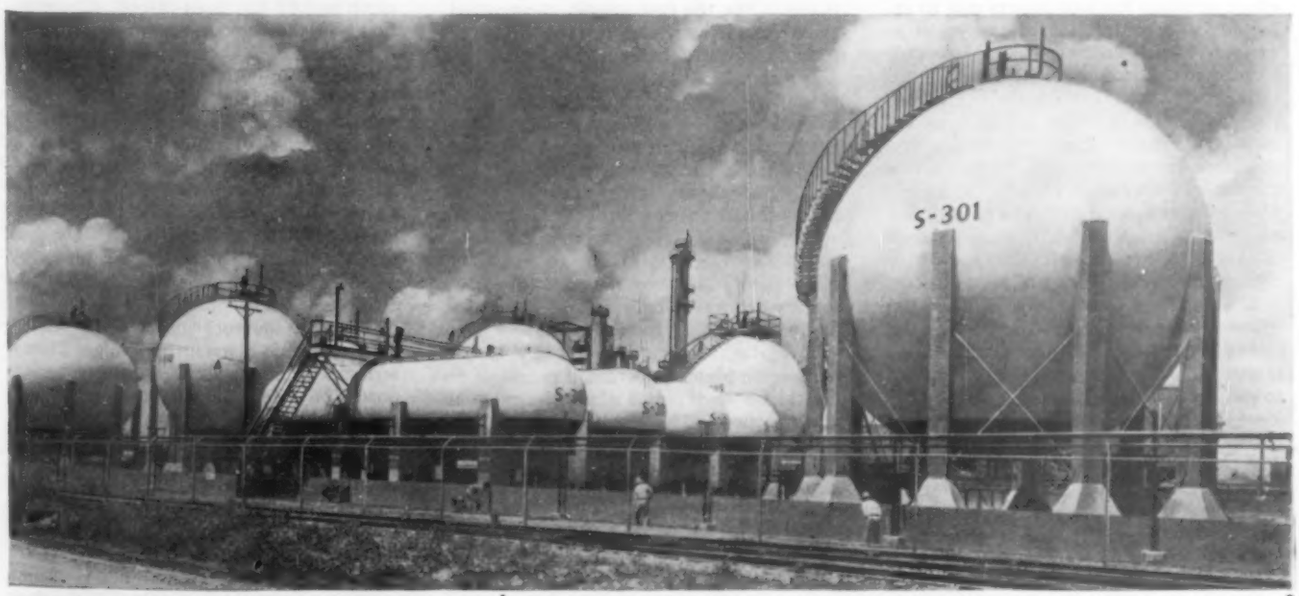

Fig. 10—Typical Medium-Pressure Storage Vessels

cates "a combination of meridional elements in tension with latitudinal elements acting as struts in compression." He arrives at his equations by a multiple integration of the shear equation which he believes is proper even though this is a thin-walled vessel. Several engineers have questioned the validity of this assumption. He states in conclusion that "use of these same equations permit rational design of tanks without a reinforcing angle being required at the junction of the conical bottom with the sides."

This is one of the points where slight plastic yielding during a hydrostatic test might eliminate or very much reduce the intensity of stresses, at this discontinuity, below the high values indicated by an analysis based on elastic deformations only.

All main welded seams joining the plates in this vessel are to be examined as fabricated in the field by radiographic means to insure that welding of the quality required for U-69 construction is maintained.

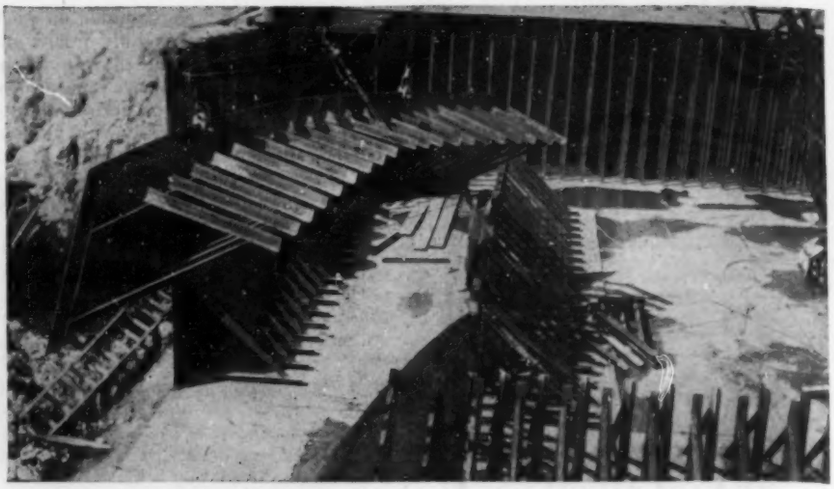

Fig. 11—Construction View Underground Pressure Vessel

Spheres and Blimps

The majority of high-pressure storage vessels are constructed as spheres or as horizontal or vertical cylinders with hemispherical or dished heads. These latter vessels are usually referred to as "blimps" or "bullets." Since these blimps are usually less economical to construct than spheres, a relatively small number of field-erected installations have been made. Many smaller shop fabricated units have been used. No important service failures of vessels of this type have been reported. Design and construction involve no difficult problems with the possible exception of design of adequate supports.

Hill[11] has recently described the largest vessels of this type of which the writer has a record. These include four horizontal cylindrical vessels, 34 ft. in diameter and 205 ft., 8 in. long, with hemispherical ends, to be used for storing gas at a gage pressure of 55 psi. The cylinders are held to shape by 2 ring girders spaced 110 ft. apart and supported by 4 columns, two being attached to each ring girder by a linkage which provides for movements due to expansion and contraction of the vessel as well as those due to wind and seismic forces. Plate thicknesses were 0.81 in. for the cylinder and 0.41 in. for the hemispherical ends. Welded seams were examined by magnetic powder testing and also using soapsuds with air pressure inside the tank to disclose any leaks. The completed vessel was subjected to an air pressure of 60.5 psi. with highly stressed parts of the vessel coated with a lime wash to indicate any overstressing of the materials.

A very large number of field-erected spheres have been constructed for the storage of both liquids and gases at high pressures. These vessels are economical to construct and have given excellent service. Except for the design of supports, no difficult design probelms are involved. The completed vessels constitute continuous, closed structures, relatively flexible and therefore able to safely withstand large concentrated loads as well as high internal bursting pressures.

The two complete failures described earlier in this paper indicate that nozzle openings and column attachments constitute 2 possible sources of weakness in such structures. If nozzles are carefully designed and fabricated so as to avoid defects and minimize residual and reaction stresses, there is no evidence to indicate that such details will cause trouble. Some engineers have suggested that nozzles should be attached to tank plates in the shop and the assembly stress relieved in a furnace to reduce locked-in stresses before shipping to the field for assembly in the vessel. In many cases this procedure would be impractical and in most cases the benefits derived would not justify the additional cost. However, such a procedure should be considered when very large diameter nozzles as for manholes are to be installed in heavy plates.

Columns attached at the the equator of spheres, which are designed to contain liquids, have been found to be the most economical type of support for such vessels. In earlier designs structural steel shapes having an H-section were generally used. These were attached directly to the shell plates or to reinforcing pad plates which were in turn attached to the shell plates. For the first vessels constructed, these connections were riveted but on all recently constructed vessels welding has been used.

In the design of column attachments, it would seem to be desirable to distribute the bearing as much as possible keeping it symmetrical and avoiding excessive rigidity and abrupt changes in plate thicknesses or other discontinuities which might act as stress raisers. The use of tubular columns attached directly to the shell plates meets these requirements in a satisfactory manner. In vessels designed for low pressure and having relatively thin shell plates, it may be necessary to use reinforcing plates or better, if practical, to use thicker shell plates where the columns are attached. The resulting attachment will then be relatively flexible and if the welding is carefully planned and executed, no serious reaction or residual stresses will be created.

It has also been suggested that the top sections of columns be attached to shell plates in the shop and the resulting assembly stress relieved in a furnace before shipping to the field. Information now available does not seem to indicate that the benefits to be derived from such a procedure would justify the additional cost. This is especially true if rigidity and discontinuities are avoided in the construction of the column attachment.

Figure 10 shows a group of typical storage vessels of these types. The supports of the spheres are encased in masonry to protect them in case of fire.

Rectangular Underground Pressure Vessel

Figure 11 shows a construction view of a large rectangular underground pressure vessel designed to operate by the "Aqua Floatation System" with a hydrostatic pressure of 45 psi. acting at the top of the vessel. The tank is 85 ft. square and 12 ft. deep with $^1/_2$-in. thick sides and roof and $^9/_{16}$-in. thick bottom, the plates consisting of A.S.T.M. A-70 steel of flange quality. It was, of course, necessary to brace the tank internally in order that the flat plates might withstand the high bursting pressure. The tank was actually tested with a hydrostatic pressure of 70 psi. before any earth backfill had been placed. Construction was completed in accordance with the A.P.I.-A.S.M.E. Code for Unfired Pressure Vessels. However, neither this code nor the corresponding A.S.M.E. Code give rules covering the design of this type of pressure vessel. Under the test pressure of 70 psi. and with no support from surrounding earth, the roof plates of the tank must resist biaxial tension stresses equal to about 5100 lb. per lineal inch. The roof plates were tied to the bottom plates by angle columns or ties spaced 18 in. on centers. These angles were welded directly to the roof and bottom plates. There were no distributing pads. Thus a series of bending stresses were superimposed on the uniform tension stresses noted above. It is difficult to predict the actual maximum intensity of the resulting combined stresses. However, analysis by conventional methods would indicate stresses approaching the yield point of the material. The sides and corners of this tank were braced as shown in Fig. 11 by diagonal ties connecting stiffening beams consisting of T-sections welded to the shell plates so as to form H-section beams.

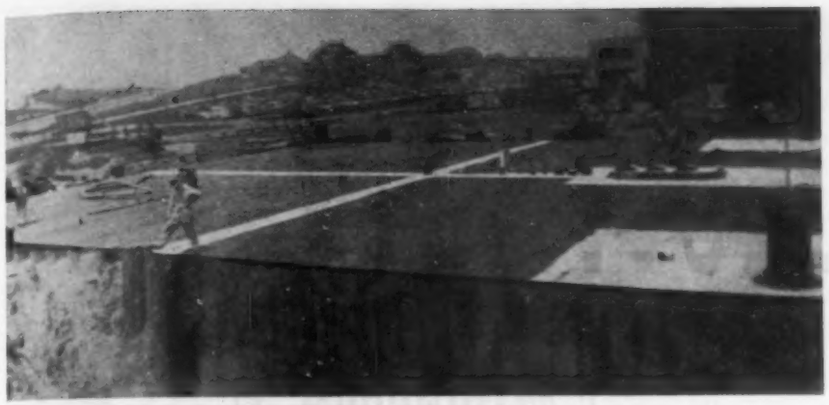

Fig. 12—Brittle Coating for Hydrostatic Proof Test of Pressure Vessel

These stiffening beams were not made continuous so that the resulting structure would be less rigid and therefore better able to withstand high internal pressure and some deformation without the creation of high deformation stresses.

In order to demonstrate the adequacy of the design under unusually severe test conditions, the completed vessel was given a proof hydrostatic test under a pressure slightly in excess of $1^1/_3$ times the design pressure. Typical and critical areas of the tank plates are shown in Fig. 12 coated with lime wash for this test. Figure 13 shows a group of nozzles and a raised section of the roof which introduced severe discontinuities. Nozzles for the manholes located at each corner of the tank may be noted in Fig. 12.

The hydrostatic test pressure at the top of the tank was increased to a value of about 50 psi. and then by small increments to a final value of approximately 70 psi., the tank being carefully inspected after the application of each load increment to determine if any plastic yielding had occurred. Such yielding would have been indicated by strain lines or by the flaking off of the brittle coating. After the final pressure had been held for sometime, it was released and the tank was emptied so that a thorough inspection of the inside could be made to determine if any plastic yielding had occurred or if any of the braces or welding showed signs of having been damaged. No evidence of damage or excessive yielding was discovered during the test or by the subsequent inspection inside the tank and the construction was approved for service by the inspection authorities.

Mill tests of the plates used in the construction of this tank gave an average yield point stress of 37,900 psi. with a minimum value for any one plate of 35,850 psi. Peterson[12] has discussed the theories of plastic failures in bending, pointing out that the usual assumption that yielding will occur when the stress in any fiber of a steel structure reaches the intensity given for the yield point by a standard tension test is false. "Yielding does not occur until higher stress intensities are reached when the distribution of stress over the critical section is not uniform. The stress at which yielding occurs is dependent on type of stress distribution and the shape of the cross section under stress." Tests by Peterson and others seem to indicate that for a rectangular cross section subjected to pure bending the yield point stress is more than 40% greater than the value given by the tension test. Kuntze[13] gives a method of determining this apparent increase in yield point for different types of cross sections.

If this increase in yield point occurs, then stress concentrations may be less dangerous since yielding is determined by stress distribution over an entire cross section rather than by stress at an isolated point.

Pressure Vessel Research Program

In this paper the writer has attempted to point out some of the variable factors which influence the economy and safety of field-erected pressure vessels. Additional basic information about some of these factors would enable engineers, fabricators and erectors to design and construct more economical vessels of assured safety. A group of engineers organized under the Welding Research Council is now planning a very broad pressure vessel research program. The studies and tests to be included in this program will be selected to cover four major divisions: Materials, design, fabrication, inspection and testing. It is to be expected that the efforts of this group may produce at least partial answers to some of the problems for which we now have no simple solutions.

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Fig. 13—Nozzles and Raised Roof Section of Underground Tank

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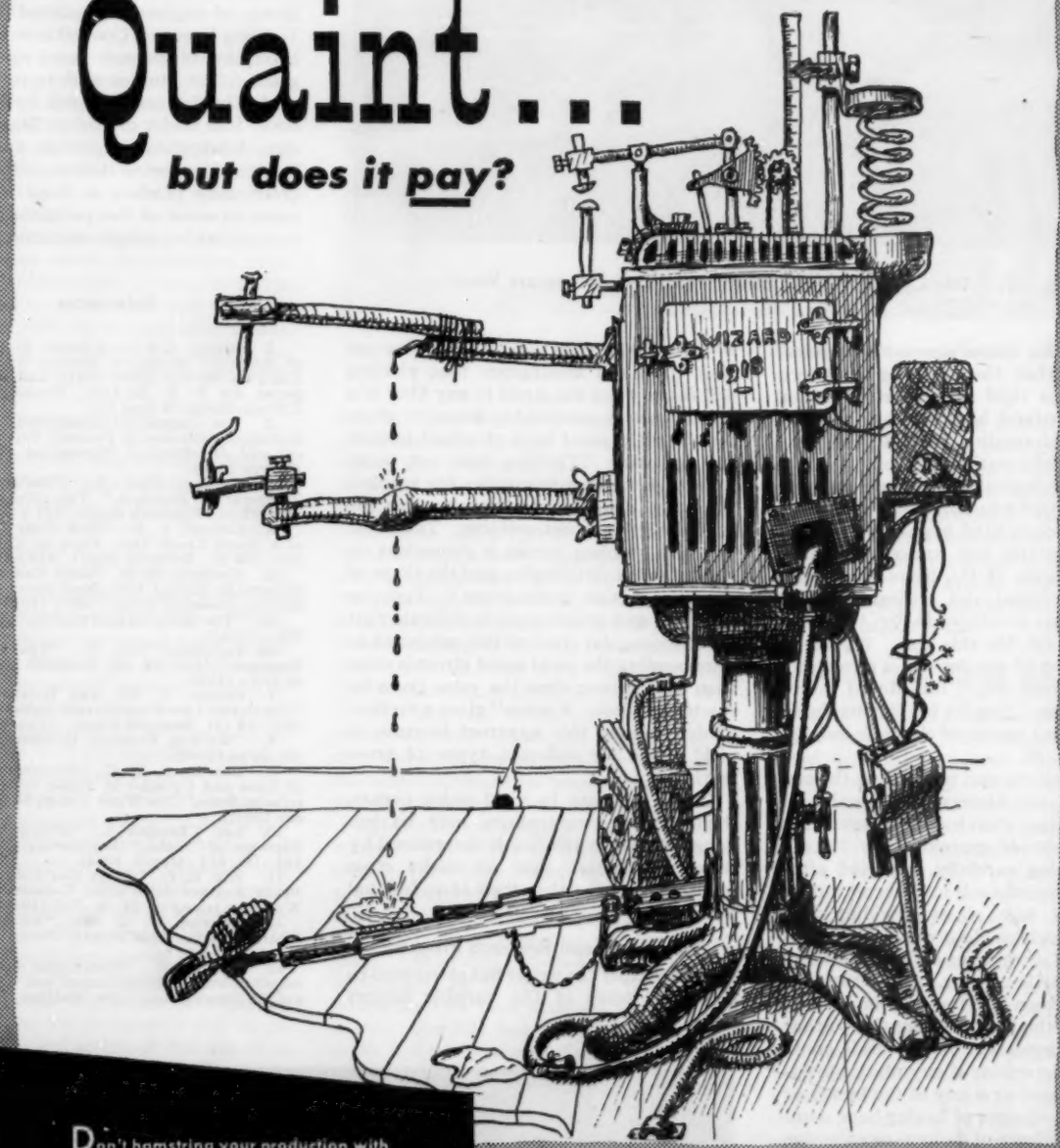

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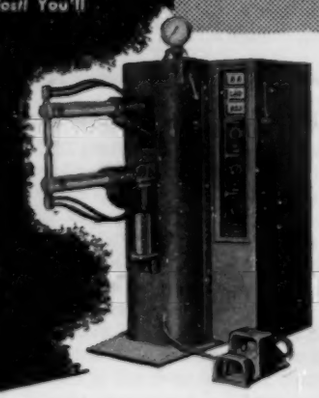

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Recent Trends in Concepts of Design for Welded Steel Structures*

By LaMotte Grover†

A NUMBER of rather new and very important concepts of design for steel structures have arisen during the last few years as a result of studies of the behavior of steel materials in actual structures as well as in testing and research laboratories. Although the field of application of the principles developed is by no means confined to welded construction, these principles will be discussed more particularly in this paper with respect to their application in the design of welded steel structures.

Many of these studies have been centered upon the behavior of steel in a member after it passes the proportional limit and the yield point and before the member reaches its point of maximum strength, where under some circumstances fracture may occur with little deformation, and under other circumstances, excessive plastic deformations occur, for example, the necking and stretching of a standard tensile test coupon or the failure of a beam by excessive deflections or collapse. The behavior of a material in a structural member usually differs greatly from that of a coupon of the same material. (Compare Fig. 3 and 6.)

Some writers have emphasized the importance of strains or deformations beyond the yield point, to the extent that they have virtually deplored the fact that conceptions of stress and the elastic theory of design ever became so deeply rooted in design practice. However, when one tries to think exclusively in terms of strains and deformations, he eventually finds himself without fully adequate explanations of behavior in many cases.

The discussions in this paper are in no way intended to condemn present design theory. They are intended merely to point out some of its shortcomings, and some instances when it can be supplemented or improved to good advantage.

It is hoped that this paper may stimulate discussion by others, which may lead to further research where it is needed to establish confirmed conclusions and the proper limitations within which they can be applied to design by practical and reasonably simple methods. Throughout the paper and at its end, examples are cited which call for further investigation.

Much attention has also been focused recently upon the behavior under applications of stress repeated many times (fatigue loading) and upon the influence of impact loading involving comparatively high velocities of load application and rapid rates of deformation in the material. However, experience with actual structures, correlated with the results of research and traffic surveys, indicates that there are comparatively few members of highway bridges, and not as many members of railway bridges as one might think, that are subjected in their service life to real fatigue conditions. Probably none of them are subjected to sufficiently rapid deformations caused by impact loading to warrant any provisions for impact other than suitable dynamic increments of the assumed loads. There seems to be evidence that with the exception of structures that are subjected to very high velocities of loading such as from gun fire, the rates of deformation encountered are not sufficiently high to require much recognition in connection with the fundamental behavior of the steel material.

Notch-Effects and Stress-Raisers

Out of all the results of experience and research that have been studied, one general factor stands out so prominently that it virtually overshadows all the others because of its interrelation with them and its effect upon some of them. This is the geometrical notch or stress concentration factor, arising from defective details of

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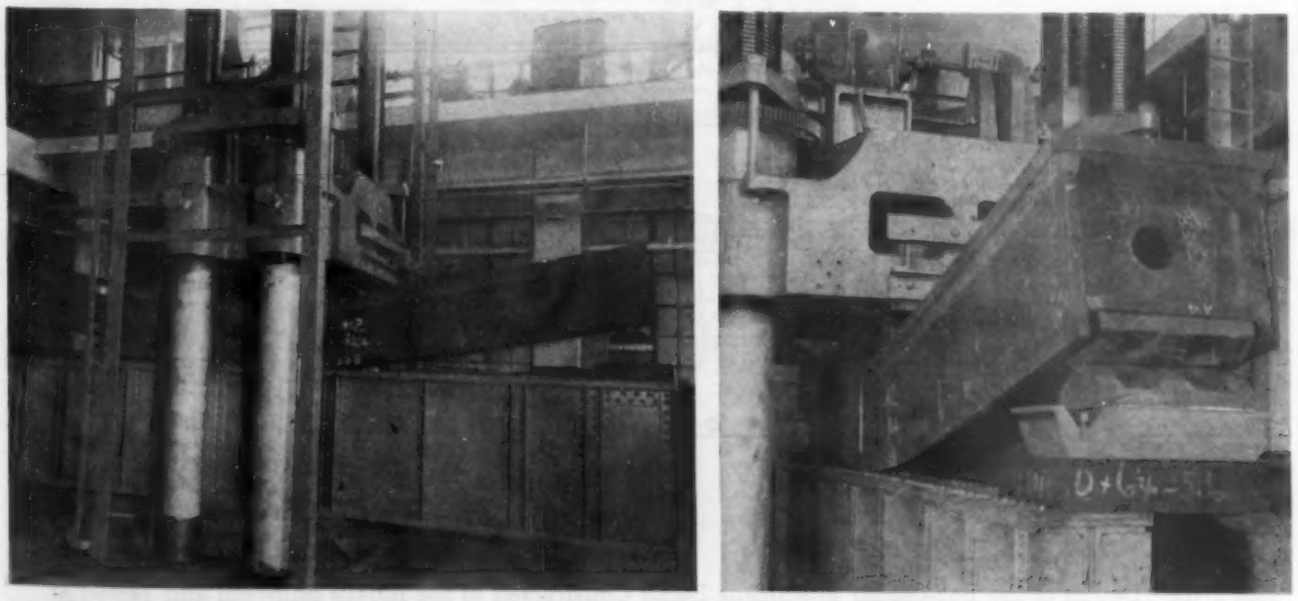


Fig. 1 (*a*)—One of a Series of Six 9-Ton Welded, Structural Carbon Steel Box Girders Being Tested at the National Bureau of Standards. This One, Constructed of Fully Killed Steel and Tested at Room Temperature, Had Deflected 18 In., and Had Not Fractured When the Applied Load Leveled Off at 1685 Kips

design or serious defects in workmanship, which may be said to cause interruptions or very abrupt changes in stress paths, using terminology that is most familiar to designers of steel structures. An obvious and inseparable part of this factor is the inherent characteristic behavior of the material in the presence of such notches or abrupt changes in section.

Admittedly of considerably more importance, in general, for cases of dynamic loading such as fatigue, stress concentration factors have received a good deal of attention, although not enough, in the design of bridges, railway rolling stock, machinery, crane girders and similar structures when a large part of the stress is produced by transient loads that cause many repetitions of stress closely approaching the maximum. The importance of stress concentration factors has received comparatively little attention in the past on the part of designers of ships, buildings, storage tanks, towers, etc., in which the behavior of the material appears to be virtually the same as under conditions of static loading and steady stress. It has now become quite widely recognized, however, that notch-effects and stress concentrations can be of very great importance in statically loaded structures under some circumstances.

A notch, a sharp re-entrant corner or any abrupt discontinuity that interrupts the transmission of stresses along smooth lines, causes a high, local concentration of multidirectional stresses, even though the applied loading is uniaxial. A notch also causes deformation to be concentrated within such a small volume of metal that the capacity of the metal to deform without fracture is reached prematurely at that point.

The effects of notches and some of the other various forms of "stress-raisers" are illustrated in Fig. 2. In sketch *a* a smooth round bar is shown as necking down and elongating a good deal under tension, in a ductile manner, before failure. In sketch *b* the introduction of a notch is shown as resulting in brittle behavior of the same material, with no appreciable elongation. The manner in which multidirectional stresses are set up at the root of the notch is depicted in sketch *c*.

In sketch *d* the presence of a smooth, round hole is shown as causing stress concentrations of about three times the average stress on the net section, in the metal adjacent to the hole. If the hole is rough

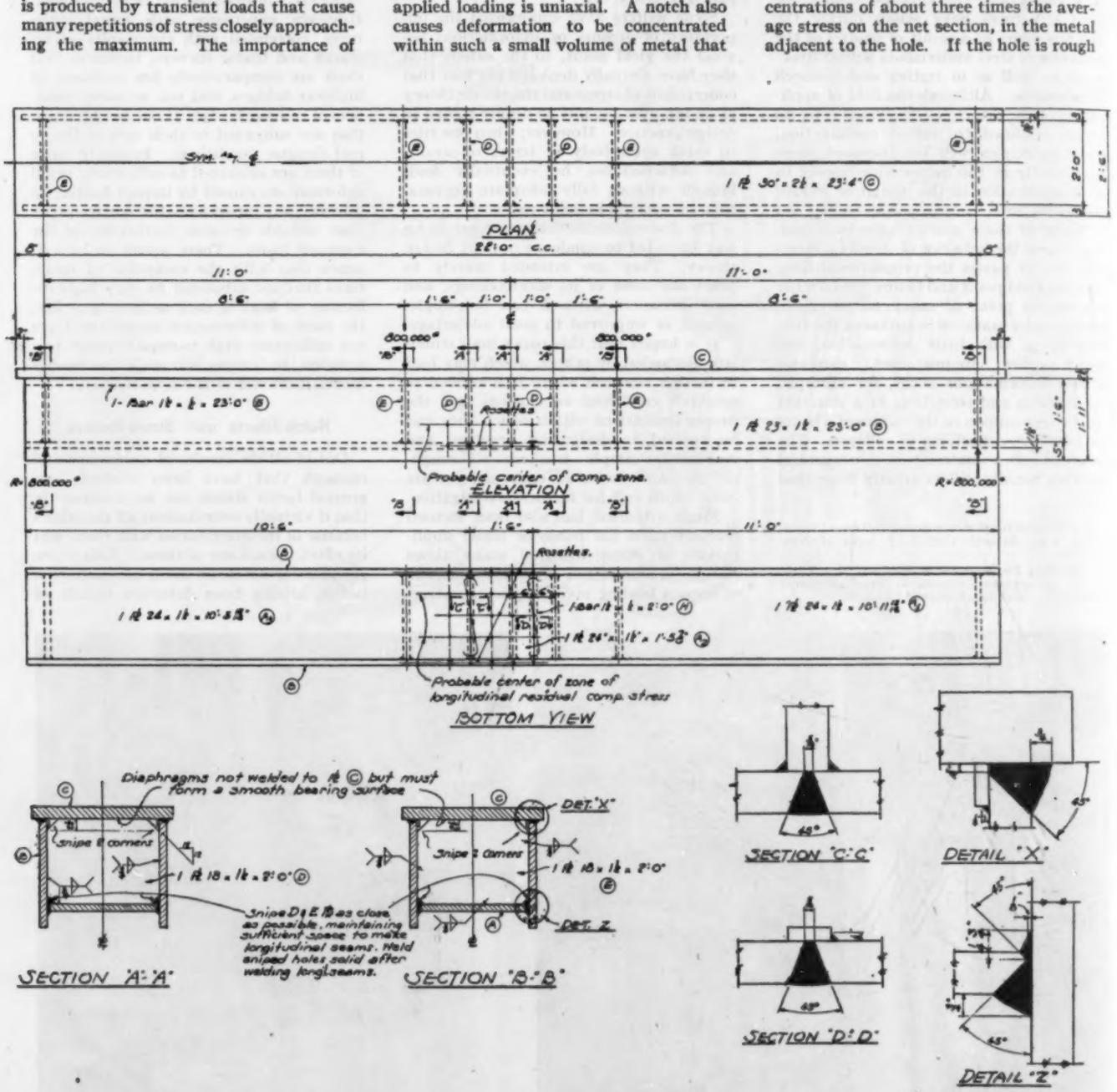

PLAN
ELEVATION
BOTTOM VIEW
Probable center of comp. zone.
Probable center of zone of longitudinal residual comp. stress
Diaphragms not welded to ℄ © but must form a smooth bearing surface
Snipe 8 corners
Snipe D & E as close as possible, maintaining sufficient space to make longitudinal seams. Weld aligned holes solid after welding long. seams.
SECTION "A-A"
SECTION "B-B"
SECTION "C-C"
SECTION "D-D"
DETAIL "X"
DETAIL "Z"

Fig. 1 (*b*)—Details of the Box-Girder Specimens Being Constructed at the Ingalls Shipyard and Tested at the National Bureau of Standards

See Research Supplement of December 1944, *Journal, American Welding Society*, for full description of the program and its objectives.

or the metal ruptured, with the presence of tiny tears, the highly localized stress concentrations may be much greater.

Any abrupt discontinuity tends to deflect stress paths sharply and cause concentrations of stress similar to the condition depicted at the 90° re-entrant corners shown in sketch *e*.

Multidirectional stresses at notch-effects and discontinuities act in a manner somewhat similar to stresses resulting from external load applied in more than one direction, depicted in sketch *f*, because they are unlike other secondary, internal stresses, in that the cause for them remains after plastic deformation has taken place, and they are not ironed out and relieved to the extent that other internal stresses, such as residual welding stresses, are relieved. The effect of these multidirectional stresses is to restrain ductile behavior and raise the yield point so that little plastic deformation can occur to redistribute stresses.

The notch-effects of butt welds that are incomplete in length or thickness of the joint are illustrated in sketch *g*.

In sketch *h*, showing the ends of partial length cover-plates, the severity of stress concentrations is depicted as being increased by the presence of the 90° reentrant corners that are involved when the cover plate is made wider than the beam-flange. In sketch *j* similar stress concentrations are depicted as the result of attachments such as lateral connection plates. Test results indicate that these stress concentrations are generally less severe in the case of comparatively short attachments that carry small stresses.

Notch-like details, whether they involve welding or not, should be avoided in so far as possible, especially in the vicinity of highly stressed material such as the extreme fibers of a section subjected to bending.

When the loading of a member is very eccentric, the stress concentration effect of a notch on the same side as that of an eccentric, static, tension load may result in failure at a surprisingly low nominal stress as calculated by conventional methods.

Any pronounced scar, such as undercutting at the toe or edge of a weld (especially if it is transverse to the direction of stress), causes high stress concentrations.

When a material is stressed in more than one direction it can manifest less ductility than under uniaxial stress. A very high degree of local, multidirectional rigidity or constraint due to geometrical shape of structural details and arrangement of welds can result in passive or secondary multidirectional stresses somewhat similar to those in the vicinity of a notch, although usually much less severe (Figs. 1 and 6). This conditions tends to prevent the localized yielding that is desirable for proper redistribution of stress. Very thick material, in itself, constitutes a considerable degree of constraint.

One of the most impressive examples of the tremendous importance of notch-effects and stress concentrations resulting from details of design is afforded by a comparison of the performance of Liberty ships built during the early part of the war-production program, with the performance of the Victory ships of improved details of design that were built in large numbers during the latter part of the program.

The most important changes made in details of design were the rounding of hatch covers, the elimination of stress raisers at attachments to the gunwales, and improvements in the layout of joints in deck and shell plating that were dictated in part at least, to facilitate sound welding, thus eliminating notch-effects due to faulty workmanship.

Also, in view of the fact that some cracks had been experienced in Liberty ships, a riveted gunwale joint was introduced as a precautionary measure in the design for the Victory ships, to discourage the propagation of any cracks that might occur.

The record of the Liberty ships is really an admirable one when analyzed from the viewpoint of the percentage of ships in which structural casualties occurred, especially when the unusual conditions of wartime production and operation are taken into consideration. However, there were enough casualties of Liberty ships to afford a significant comparison with the complete absence of any serious casualties reported up to this time for Victory ships.

Of the three general factors—design, materials and workmanship—that influence the behavior of any kind of structure subjected to given service conditions, details of design seem to be clearly indicated as one of the most important—and probably the most important—factor that may be credited with the greatly improved structural behavior of the Victory ships. This emphasis upon the influence of design seems warranted, after according a great deal of credit to important and substantial improvements in workmanship (which eliminated some notch-effects), and with due regard for better average service conditions later in the war when ships had to be sent less frequently into colder, northern climates, and when other operating conditions became less severe

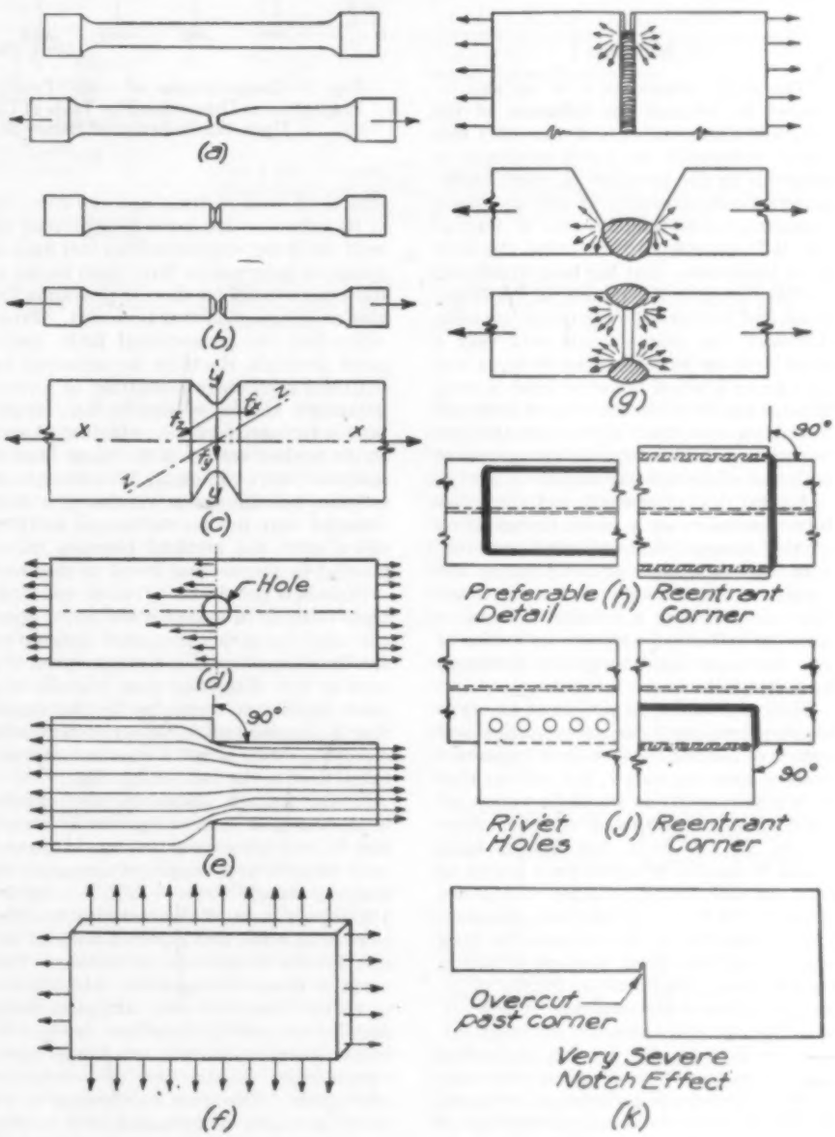


Fig. 2—Notch-Effects and Stress Concentrations

Note: Stresses depicted by small arrows in sketch (g) are stresses due to load. They are not residual stresses.

as the submarine menace became less serious, and the crews of the ships learned better how to handle them and were not forced by circumstances to subject their ships as often to unusually severe service conditions.

In considering the behavior of welded ships, as compared with that of bridges and buildings, it should be kept in mind that an ocean-going welded ship is a very large structure with all structural parts joined together in a virtually monolithic manner, and with some of the parts subjected at times to greatly different temperatures from those of other parts; for example, the upper body as compared with the lower part of the hull that is under water, and the outside plating as compared with the engine room, or as compared with refrigerated compartments with structural parts exposed to the colder atmosphere. It would seem that under these service conditions of differential temperature, quite large temperature stresses must be set up in parts of the ship's structure.

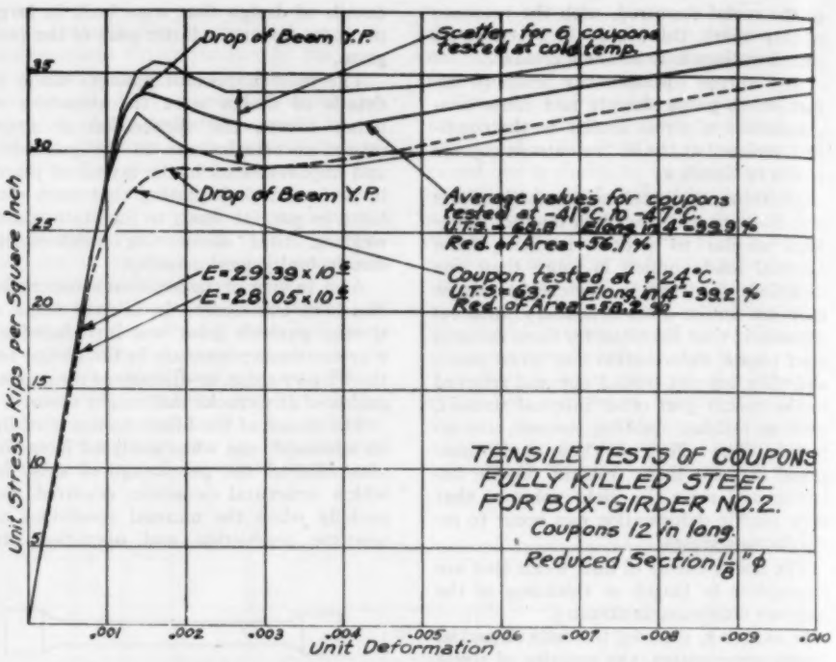


Fig. 3—Temperatures of —40° Produce Comparatively Small Changes in Tensile Properties as Determined by Tests of Coupons, But They Exert an Important Influence Upon the Behavior of Heavy Structural Members (see Figs. 6 and 10)

Materials

The above discussion is in no way intended to relegate the influence of the inherent characteristics of the steel material, principally its notch-toughness or behavior in the presence of notch-effects or stress concentrations at various service temperatures or temperatures of testing; nor is it intended to minimize the very great importance that has been attributed to this factor in the reports of investigations and research during recent months. Although this characteristic may vary a great deal for various types of steels and for various heats of the same kind of steel, average conditions in this respect must not have been very much different in the construction of the Victory ships as compared with that of the Liberty ships.

A great deal of research and study has been devoted recently to the investigation of this characteristic of steel material, with the viewpoint of determining the minimum notch-toughness that is desirable, and devising a suitable acceptance test that will afford a reliable indication of the degree of notch-toughness possessed by a material.

Since the service conditions of any type of structure, such as temperature and nature of loading, have a very important bearing upon the matter, it is evident that such requirements as would be warranted for a structure subjected to very severe impact at extremely low temperatures would be needlessly severe for a bridge or for a statically loaded structure that is not subjected to as low service temperatures. For the latter type of structure, the very appreciable additional cost of imposing equally severe requirements for the physical properties of the materials, in general, would surely be unwarranted and wasteful.

There is a rapidly growing realization that the designer of engineering structures must acquire a more accurate and intimate knowledge of the fundamental behavior of the materials that he uses and how they behave in various kinds of structures and members, if he is to do a thoroughly intelligent job of safe and economical design. The conventional acceptance tests for structural steel material and the concepts of its behavior that have been derived by most designing engineers from this limited source in information have been found in some cases to fall far short of providing the kind of information that is needed. Properties like the proportional limit, yield-point strength, ductility as measured by the total percentage elongation of a comparatively narrow or slender bar, toughness as measured by the reduction of area at the necked section of the same kind of specimen, have commonly been thought of as quite definite characteristics of a steel material that remain unchanged in their effect when the material becomes incorporated in a structural frame or member.

Although provisions of steel specifications relating to ductility are based upon the total elongation measured clear up to the breaking point of a test specimen, the part of this elongation that is really the most significant seems to be the strain that is sustained up to the ultimate tensile strength, which is not a constant proportional part of the total elongation.

Where impact resistance and notch-toughness have been recognized as important in steel structures that are subjected only to ordinary ranges of atmospheric temperatures (−40 to +120° F.), notch-bar impact tests of the materials usually have been made and reported without regard for the temperature of testing. The range of temperatures within which quite an abrupt transition may take place from ductile to brittle behavior frequently encompasses or lies near to average room temperatures in the case of commonly used steels. Therefore a difference of 10 or 15° in testing temperature often results in a very great difference in notch-bar toughness or impact strength (Fig. 4).

As a matter of fact, all of these characteristics and the behavior of the material in actual structures vary greatly, depending upon the geometrical shape of details and upon the size and proportions of members which affect the direction and distribution of the stresses, and depending upon other conditions such as service temperature. Even ultimate strength cannot be thought of as a definite, invariable property. These facts seriously upset some of the commonly prevailing conceptions of safety factors and balanced design, and they call for a reorientation of many concepts of design.

The thought of even small strains beyond the elastic limit or yield point occurring occasionally in the material of a structure at certain points, distasteful and harrassing as it may seem to some designers, should, on the contrary, be a comfort to them under many circumstances with the assurance that stresses and moments are being distributed more nearly into the pattern that has been assumed in the design calculations, or into a more favorable pattern.

The degree of notch-toughness that is required in a steel material to insure its satisfactory performance depends upon a number of factors or conditions that may be peculiar to the kind of structure involved, including its details of design, its anticipated service conditions, such as nature of loading and service temperatures and, to some extent, the control exercised over workmanship. The three general factors are recognized as:

1. Service temperature (usually of little importance, if any, in building construction, but important for bridges, construction and handling equipment, etc. when they serve in cold climates).

2. Strain rate (generally considered to be of comparatively little importance in ordinary types of bridges or buildings because of the comparatively slow rates of deformation encountered).

3. Biaxial or triaxial loading or con-

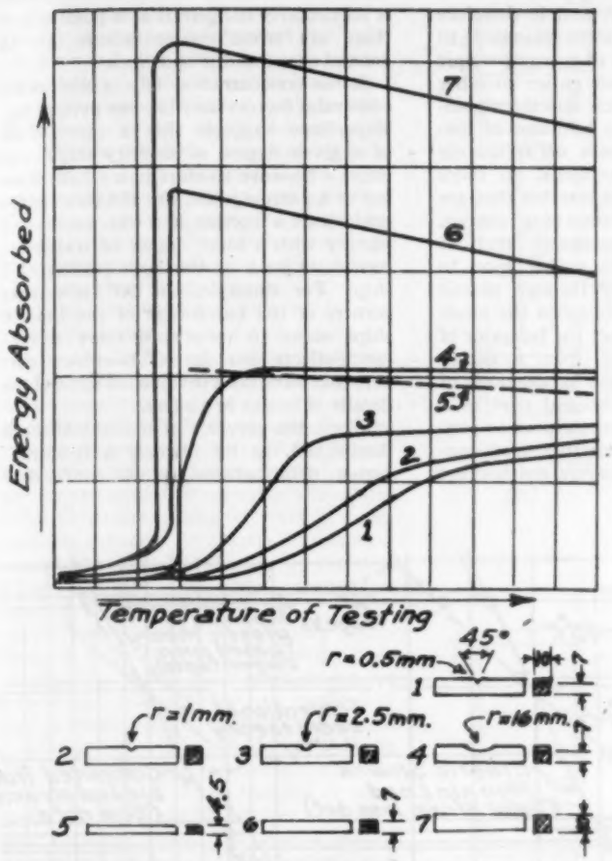


Fig. 4 (*a*)—Typical Temperature-Energy Curves for a Metal Such as Steel or a Zinc Alloy, Illustrating the Effect of Various Degrees of Constraint

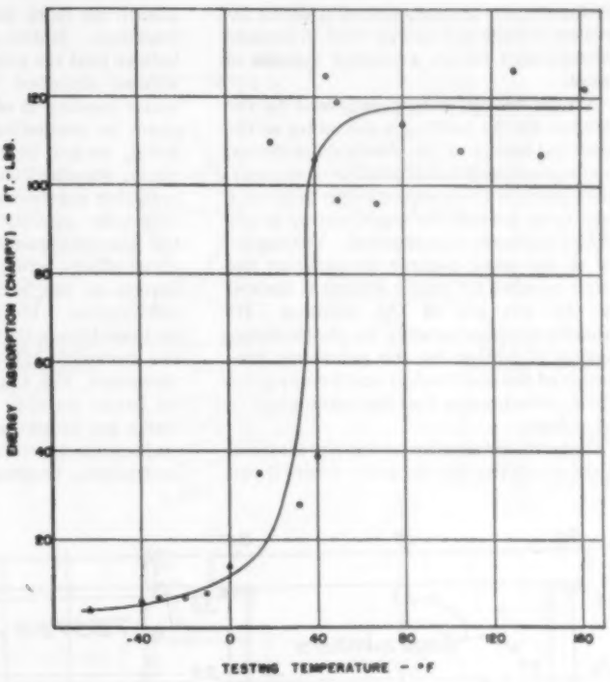


Fig. 4 (*b*)—Typical Charpy (V-Notch) Test Results for Structural Steel Material of Beams for Drop-Hammer Flexural Impact Tests at Columbia University

Note: Fig. 4(*a*) after (Erdman-Jesnitzer and Hoffman. See report by Gillett and McGuire on "Behavior of Ferritic Steels at Low Temperatures," Part I, p. 43, Published by A.S.T.M., December 1945.)

straint. (*a*) Degree of constraint against plastic deformations, resulting from notch-like details (introduced in the design or occurring inadvertently during construction), or from size, geometric shape and proportions which may cause biaxial or triaxial constraint and localized secondary stresses. Severe plastic strains previously imposed tend to limit the plastic deformations that can be sustained later. (*b*) Degree of biaxiality or triaxiality of the applied stress or loading.

Factors 1 and 2 need no further discussion with regard to bridge and structural work, except to say that under some conditions, for example, in the presence of a rather severe notch-effect, temperatures not much below room temperature may be of some significance; and it appears that the subzero temperatures to which many of our northern bridges are subjected are a very important factor.

With reference to factor 3 (*a*), it seems that for the size and proportions of ordinary structural members, no great importance need be accorded to biaxial or triaxial constraint due to general shape. The investigations of welded beam-end connections of the Welding Research Council, at Lehigh University, involving full-size rolled beams, indicate that when connections are properly designed they are capable of sustaining quite large plastic deformations without structural damage. However, the importance of notch-effects (usually a matter of details) cannot be too greatly stressed. Also when heavy members of special cross-sectional shape or arrangement are used, for example, box sections, and when thicknesses of material are encountered that are considerably greater than those commonly used, some apprehension is warranted, partly because of the geometric effects and partly by reason of the less favorable inherent characteristics of the steel material that are likely to be found in material of greater thicknesses.

The degree of triaxiality of applied stress or loading, 3 (*b*), is not usually severe in a bridge or building with the possible exception of a few details, such as the restrained connection of a girder to the tension flange of the leg of a rigid frame, or the intersection of tension flanges of bridge girders (Fig. 5), or perhaps the case of a wide steel plate decking on a bridge, if arranged so that is is subjected to as much transverse restraint as that in the deck of a ship, which appears to impose transverse stresses over wide areas. In structures like spherical shaped tanks, the degree of triaxiality of loading seems to be severe enough to warrant careful consideration.

The main service condition, other than temperature, that warrants special consideration in determining the required notch-toughness of a constructional steel seems to be the degree of stress concentration and constraint, particularly that resulting from notch-effects which cause high concentrations of stress and restrict deformations to a small volume of metal. One viewpoint of the effect of these stress concentrations is that the accompanying local constraint is so severe against deformations which could relieve the high peaks of stress that the stress continues to build up to the fracture point. This is not difficult to imagine when one considers that stress concentration factors of three or more have been measured even at the edge of a smooth round hole and as high as ten for some re-entrant corners.

Another viewpoint is that a certain amount (often a small percentage) of the total energy input from the loading of a structural member (not necessarily an impact loading) is delivered to a small volume of metal in the vicinity of the notch-effect.

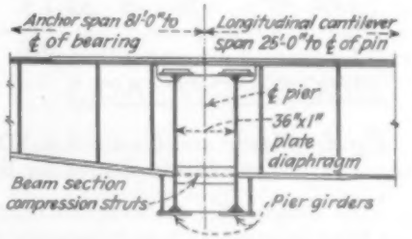

Anchor span 81'0" to ℄ of bearing
Longitudinal cantilever span 25'0" to ℄ of pin
℄ pier
36"x1" plate diaphragm
Beam section compression struts
Pier girders

Fig. 5—Junction of a Longitudinal Cantilever Bridge Girder with a Transverse Cantilever Supporting Girder, Over Pier of All-Welded Connecticut Grade-Separation Structure

Note openings coped in web of longitudinal member to relieve local geometric constraint near tension flanges of both girders.

As the degree of sharpness of a notch increases, strains and energy tend to become concentrated within a smaller volume of metal.

A part of the energy delivered to the member by the loading is stored up as the potential energy of the elastic deformation (a comparatively small amount of energy). After parts of the member begin to yield, a very large part of the input energy is absorbed in plastic deformation. The capacity of the small volume of metal at the notch to store up elastic energy is limited by the strength of the material. Its capacity to absorb energy by plastic deformation is limited by the geometric constraint of the notch-effect and by any prior plastic deformation that has taken place in the volume.

Under these circumstances the material at the notch reaches the point where it can absorb no more energy, and it therefore fractures. It does not seem reasonable to believe that the amount of energy per unit volume absorbed by an entire member under loading is of much specific significance in evaluating the behavior of material, except in the case of accurately made, standardized specimens. If there are other portions of the member that are especially capable of absorbing energy, the portions containing details such as notch-effects will not be called upon to absorb as much energy through plastic deformation. It appears to be the localized conditions that affect the behavior of the material. However, from a design viewpoint, the shape and proportions of an entire member or integral part of a frame are important with respect to general tendencies toward creating stress concentrations, because a severe notch-effect is particularly dangerous at a point where there are stress concentrations due to general shape and proportions.

Stress concentration effects and other constraint factors may become pyramided. Experience suggests that a notch-effect of a given degree of severity might not cause a fracture to start in a small member or a narrow plate, but the same notch could start a fracture in a wide expanse of plating with a large degree of transverse constraint such as the deck plating of a ship. For example, the 90° re-entrant corners of the hatchways of the Liberty ships seem to constitute more serious notch-effects than the 90° re-entrant corners that have been involved in some of the details of beams or girders.

When the severity of a notch-effect is diminished, as by filleting a re-entrant corner, deformations are not confined to

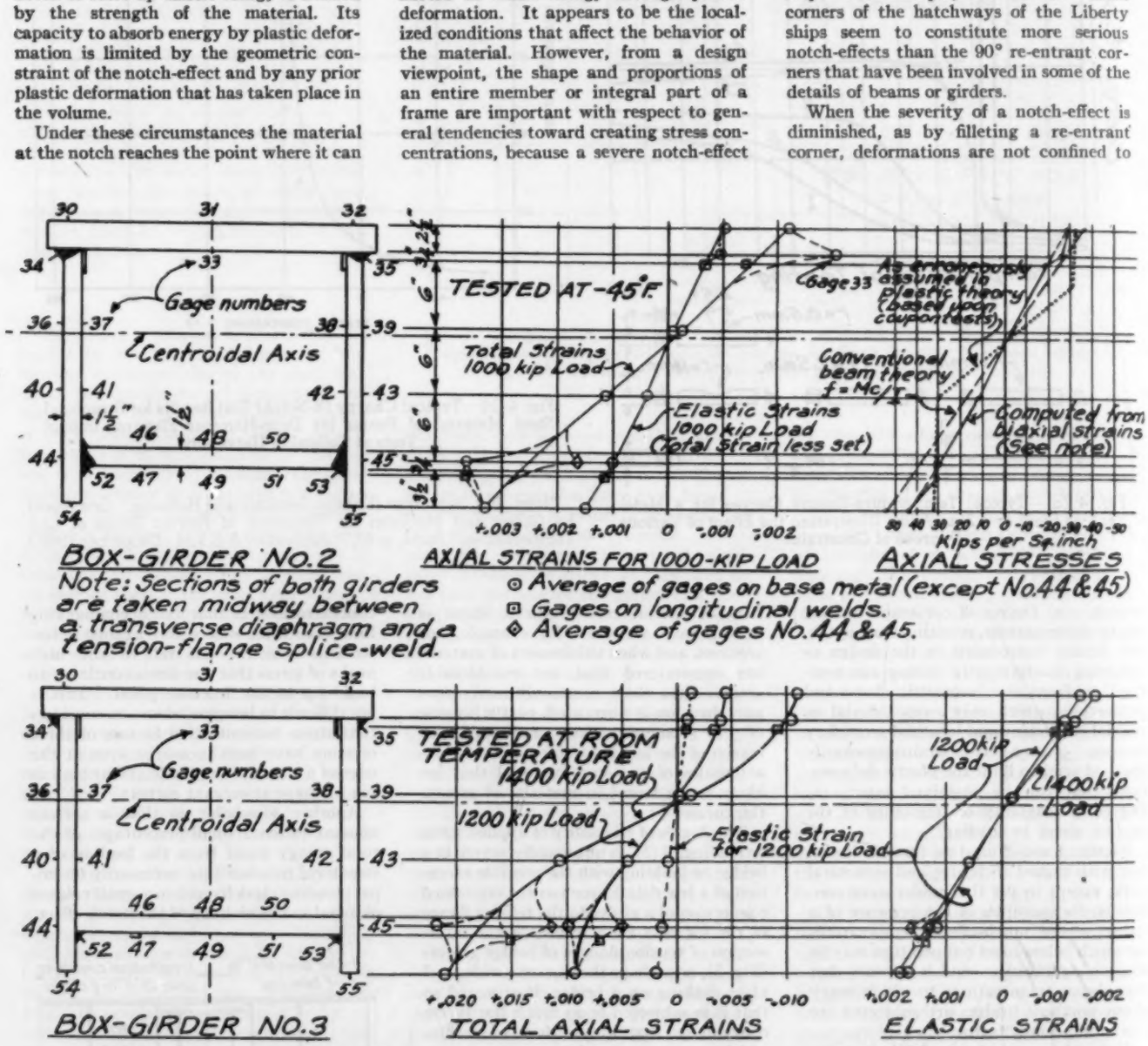

Gage numbers
Centroidal Axis
TESTED AT -45°F.
Total Strains 1000 kip Load
Elastic Strains 1000 kip Load (Total Strain less set)
Gage 33
As erroneously assumed in plastic theory (based upon coupon tests)
Conventional beam theory f = Mc/I
Computed from biaxial strains (See note)
BOX-GIRDER NO.2
AXIAL STRAINS FOR 1000-KIP LOAD
AXIAL STRESSES
Kips per Sq. inch
Note: Sections of both girders are taken midway between a transverse diaphragm and a tension-flange splice-weld.
Average of gages on base metal (except No. 44 & 45)
Gages on longitudinal welds.
Average of gages No. 44 & 45.
Gage numbers
Centroidal Axis
TESTED AT ROOM TEMPERATURE
1400 kip Load
1200 kip Load
Elastic Strain for 1200 kip Load
1200 kip Load
1400 kip Load
BOX-GIRDER NO.3
TOTAL AXIAL STRAINS
ELASTIC STRAINS

Fig. 6—Plastic and Elastic Axial Deformations and Axial Stresses, as Measured with SR-4 Electric Resistance-Type Strain Gages for Box Girders Nos. 2 and 3, National Bureau of Standards Program

Note that elastic relaxation strains are approximately proportional to distance from neutral axis, rather than the total deformations as commonly assumed in the plastic theory of design for flexure. However, the deflections and changes in shape and curvature were sufficient to satisfy the essential requirements of the theory, with an ample margin of safety in the cases of Box Girders Nos. 1 and 3.

Note: The axial stresses, computed from the measured biaxial strains, as shown above for Box Girder No. 2, do not quite provide the internal resisting moment required for equilibrium. It is possible that under the prevailing conditions, the SR-4 electric strain gages did not relax elastically quite as much as the steel of the girder. Also the average stress across the $1^1/_2$-in. thickness of material may differ slightly from the average of the surface stresses as measured. Although the end bearings slipped somewhat, there was likely a horizontal thrust which would act to reduce the mid-span moment.

as small a volume of metal as when the notch is sharper, and consequently a greater amount of adjustment can take place around the notch through plastic deformation. Long experience has proved the advantage of filleting such corners. In structural tests of the Liberty ship S.S. "Philip Schuyler," reported by John Vasta of the U. S. Maritime Commission, strain measurements made during loading showed quite high stress concentration factors even for rounded hatch corners, but the strains were much less localized than those at square hatch corners.

Plastic deformations in the vicinity of a notch-effect seem to exert two influences, one for the better and one for the worse. Firstly, they tend to readjust and redistribute stresses and reduce stress peaks, and at the same time the fracture strength of the metal is increased by the work hardening. Secondly, they cause work hardening and use up the available capacity of the material to deform plastically when in many cases its capacity for plastic deformation is already reduced drastically by the constraint of the notch-effect. Quite frequently, a small area of fibrous or ductile type of fracture is found at the very beginning of a brittle crack, suggesting that plastic deformation could start, under the prevailing conditions, but was confined to such a small volume of metal that it did not succeed in averting fracture. Perhaps the severity of the notch-effect was not enough to start a brittle fracture at once, under the other conditions that prevailed, such as temperature; but after a certain amount of concentrated plastic strain and work-hardening had occurred, a shear failure started, creating a sharper notch, in the form of a crack, that could start a brittle fracture.

It appears that a moderately severe notch-effect, such as a rounded hatch corner in the deck plating of a ship, may produce high enough stress concentrations to cause quite large plastic deformations over a considerable area in the vicinity of the notch while the material some distance away from the notch-effect undergoes no plastic deformation. Perhaps this can be thought of as a greatly magnified picture of what often happens at a sharper notch, during earlier stages before fracture starts.

In any practical construction there must be a balanced, economic relationship between materials of construction, design features and standards of workmanship. Regardless of the materials, methods and processes used for construction, they will unavoidably fall somewhat short of perfection as a matter of practicability. Also, if a structure were designed and its parts detailed so as to be almost technically perfect, its arrangement would in most cases have to be made so impractical that it would be virtually worthless.

The degree of technical perfection in design, materials and construction procedures must always be a matter of economic balance and compromise, to insure the required margin of safety at the least cost.

Any improvements that can be specified in materials of construction, which can be effected in a practical and economical manner, to improve the effective ductility and the ability of the material to distribute

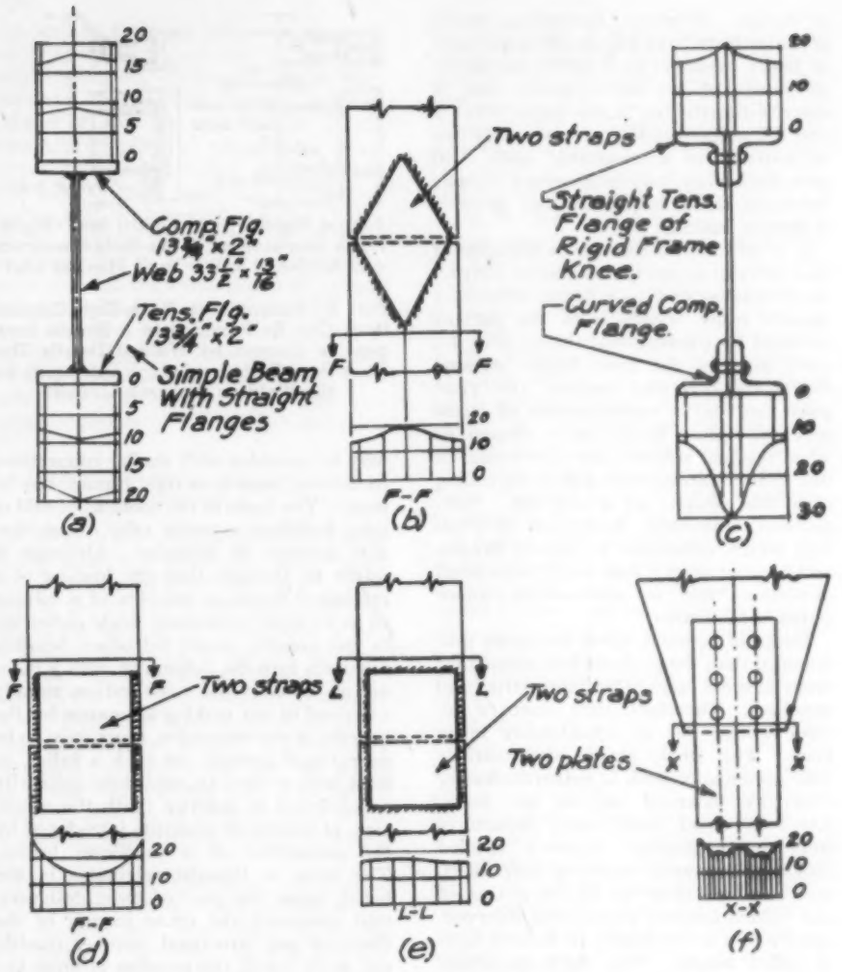


Fig. 7—Effects of Some Details of Design Upon Transverse Distribution of Load-Stresses, Which Exerts an Influence Upon Fatigue Resistance, Apart from Any Notch-Effects Involved

(a) "Test of an Arc Welded Girder," A. V. Huggenberger, Schweitzer, *Bauzeitung*, 98 (26) (Dec. 26, 1931).
(b), (d) and (e). "Distribution of Stresses in Welded Double Butt-Strap Joints," Hollister and Gelman, *Journal of American Welding Society*, October 1932, pp. 24 to 31.
(c) "An Investigation of Steel Rigid Frames," Lyse and Black, *Trans. Am. Soc. C. E.*, 107, 127 (1942).
(f) "Tests of Riveted Joints and Riveted Joints Strengthened by Arc Welding," Everall and Berridge, *North-Western Railway, India*, p. 771, Vol. II, 1938, *Symposium on the Welding of Iron and Steel, British Iron and Steel Institute.*

and transfer stresses properly in the presence of moderate notch-effects and other imperfections in design and workmanship, always result in more freedom in design and less restrictions or special provisions being imposed upon construction procedures, thus leading to more economical construction.

Influence of Proportional Limit, Yield Point and Plastic Deformation Upon the Behavior of Structural Members

A great deal of attention has been given in the technical literature and research of foreign countries during recent years to the so-called plastic or "elasto-plastic" theory of design, which recognizes and, under many circumstances, takes advantage of plastic deformations that occur in such a manner as to redistribute stresses and bending moments, particularly in structures with restrained connections. A theory of design which takes plastic deformations into account has also been presented by J. A. Van Den Broek, in the *Transactions of the American Society of Civil Engineers*, page 638, vol. 105 (1940).

The foregoing discussion of the effect of notches and other forms of constraint or triaxiality of stress, and the effect of temperature, has been included prior to the following discussion, to focus attention upon the fact that if reliance is to be placed upon plastic deformations for their beneficial effects, the engineer must guard against circumstances that might prevent the occurrence of such deformations (Fig. 6). Under most circumstances encountered in ordinary, properly designed and detailed bridge and building members, it seems likely that plastic deformations can occur to redistribute stresses into a more favorable pattern, and to redistribute bending moments and increase the safe carrying capacity of a structural frame with restrained connections, in the manner assumed by the above-mentioned theories

of design. However, limitations would probably have to be imposed in some cases of heavy members such as the box-girder specimens of an investigation that is described further on in this paper (Figs. 1 and 6), unless suitable special steels can be provided at a reasonable cost. Also some limitations may be necessary in cases involving elastic instability and in cases of fatigue loading.

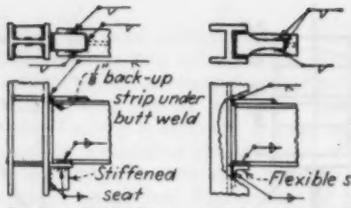
It is well known that the distribution of load stresses across the section of a structural member such as a beam, sometimes departs quite widely from the pattern assumed by conventional theory (Fig. 7), until some of the most highly stressed fibers are deformed beyond the yield point, so that a redistribution of stress may take place in the same manner as when residual stresses due to welding, or due to nonuniform cooling after the rolling of a steel shape, are ironed out. Nonuniform, transverse, load-stress distribution occurs commonly in curved flanges, and in other cases it may result from small distortions due to unavoidable minor errors in fabrication.

Peaks of residual stress are more pronounced than the peaks of load stress that occur in most cases of ordinary structural members. Therefore, they start to become ironed out at considerably lower loads. The small plastic deformations that accompany such a redistribution of internally balanced stresses are manifested by small, quite early departures from proportionality between applied load and measured strains or deflections, such as those observed in the testing of any welded beam or girder, and observed, usually to a lesser degree, in flexural tests of rolled beams. This early departure from proportionality does not seem to affect the structural behavior in any adverse manner, nor reduce the safe carrying capacity of a structural member.

In tests of welded and riveted flat-ended columns, made by Slater and Fuller* at Lehigh University, wide variations were observed in the stresses at which appreciable departure from proportionality occurred, but there was no apparent influence of the proportional limit or of internal stresses upon the maximum carrying capacity of the columns. The intermittent (stitch) welds for one of the columns were spaced, center-to-center, to provide a spacing-to-thickness ratio of 32, which amounted to about 26 on the basis of clear spacing. The cover plates buckled locally at the ultimate load, which was, however, about the same as for columns with a closer weld or rivet spacing. The average stress at maximum load (for all the columns and with no significant difference between the welded and riveted ones) was about 15% greater than the strength computed by the Rankine formula (for maximum load and yield point stress, which stress was not reached in the tests except in localized areas and with no adverse effect).

In a conventional tier building, the columns, which are usually continuous through at least several story-heights, may be afforded with a great deal of restraint by means of inexpensive welded beam connections (Fig. 8). In mill and shop buildings, the upper ends of columns

* Am. Soc., C.E., Transactions, 99, 112 (1934).



Typical Rigid Top-Plate Connection and Stiffened Seat

Typical Semi-Rigid Top-Plate Connection and Flexible Seat

Fig. 8—Restraint at Beam-End Connections Can Be Provided in a Simple Inexpensive Manner by Welded Details That Have Been Tested at Lehigh University for the Welding Research Council

may be provided with similar connections to the roof beams, or rigid frames may be used. The bases of the columns of mill or shop buildings ususally offer a considerable amount of restraint. Although it might be thought that the loading of a restrained beam on one side of a column so as to tend to produce single curvature in the column would introduce bending moments into the column in such a manner as to offset the conservatism usually exercised in not making allowance for the benefits of the constraint, there seem to be no rational grounds for such a belief, at least with respect to conditions ordinarily encountered in practice (with the exception, of course, of moments introduced by the connection of a cantilever beam). The error in thought originates in the belief, upon the part of most designers, that whenever the stress in any of the fibers of any structural member reaches the yield point, the member is upon the verge of failure.

In the Fourth Interim Report of "An Investigation Into the Behavior of Welded Rigid Frame Structures," entitled "Behavior of Stanchions Bent in Single Curvature," by J. W. Roderick with a Foreward by Professor J. F. Baker, published in Dec. 1945 by the British Welding Research Association, examples are cited to reflect the undue conservatism of British design regulations (especially with regard to rigid or semirigid construction), which regulations are similar to those followed by many if not most of the structural engineers in the United States. In the report, Dr. Roderick outlines approximate, rational methods for calculating the true axial load at failure for columns bent in single curvature, taking plastic deformations into account. These methods do not apply solely to fully rigid construction, although the benefit in behavior is derived principally from the restraint at connections. The methods used indicate failure loads that agree very well with those observed in tests.

As examples, the columns or stanchions of four frames were analyzed by these methods and also by assumptions as applied commonly in the design of conventional building frames, in which the restraint of connections as well as the moments introduced by them into the columns, is neglected, except that the column formula used is based upon the assumption of the column behaving as a pin-ended column of only 0.7 the actual length, and some bending stresses are assumed to be induced into the column by reason of the eccentricity of the beam seat or connection with respect to the center line of the column. In one of the frames the bending stresses were high enough that no axial load would have been permitted by the standard regulations, thus resulting in a factor of safety of infinity, in view of the very substantial true load for failure. Other true factors of safety ranged from this one of infinity down to 3.57, based upon the true failure load divided by the maximum load permitted under the regulations.

In applying the plastic theory of bending, plastic deformations should be taken into account, along with resulting deflections, as they actually occur in structural members and frames, rather than basing assumptions upon the behavior of tensile test coupons (Figs. 3 and 6). The application of such a theory of design would reflect the true capacity of a member after it has sustained comparatively small but in some cases rather widespread plastic deformations, instead of assuming that failure is imminent when the yield point stress is first developed in the extreme fibers.

Although the yield point stress of a steel material seems to have been proved quite conclusively to be a significant and suitable general basic criterion for establishing unit working stresses, recent research and experience have focused attention upon the fact that the yield strength value that is applicable in design is not a fixed value, but is affected considerably by stress distribution and by the shape and geometrical proportions of a member (Fig. 9), and it is greatly affected by temperature and rate of deformation. The significant yield strength value of material in a structural member, especially when it is of proportions such as to introduce considerable constraint against deformation, seems to be considerably higher than that determined by test coupons of the material.

Tests of even small rectangular steel bars, reported by F. G. E. Peterson in the April 1946 *Proceedings of the American Society of Civil Engineers*, showed yield points 40% higher than the yield points as determined from coupons.

Professor J. F. Baker has reported a 50% increase in the load required to produce large deflection or collapse of a small, simply supported beam of rectangular cross section, as compared with the load that first produces yield in the outermost fibers. For a small rolled-steel beam bent about its major axis, he states that the increase is about 15%. In this case a greater part of the section is concentrated near the extreme fibers. Although the yield values cited by Peterson are virtually proportional limits, as shown on load-strain curves and confirmed by the first appearance of Lueders' lines, his specimens were polished, and what he observed was likely the "upper yield point." He mentions a 68% increase in yield point for the case of a round bar in flexure.

It seems to be quite evident from the results of research that in structures with restrained connections the margin of safety is greatly increased as compared with simple frames, and considerably higher working stresses may be permitted in the vicinity of restrained connections,

as provided to a conservative degree by the specifications of the American Institute of Steel Construction, which, to this limited extent, recognize the elasto-plastic theory of design, or what Professor Van den Broek of the University of Michigan has termed "Theory of Limit Design."

In the static tests of welded structural steel beams, made as "control tests" in the fatigue testing program at the University of Illinois, the computed stresses at failure (by buckling of the compression flange) were as high as 59,300 psi., and when a yield point could be observed, it was considerably higher than for the plain rolled beams.

The yield strength as determined from local strains near the butt-welded splice at mid-span of one of the rolled structural steel beams tested at room temperature under static load as a control specimen of the Columbia University Impact Program (which will be described further on) was about 45,000 psi., practically the same as determined for a plain rolled beam, on the basis of an offset of 0.2% (Fig. 9). The yield strength determined on this basis for some of the other beams with welded splices was very much lower; but at a measured strain of 0.75% (0.6% offset) the beam that had shown the earliest and most pronounced departure from proportionality was carrying virtually as much load as any of the other beams, and its load deflection curve was one of the highest ones, showing that the unusually large, early departure from proportionality was quite largely a localized condition. However, even the load-deflection curves showed a somewhat earlier departure from proportionality for the welded beams, although it did not affect their capacity to carry load.

A further example taken from the previously mentioned Fourth Interim Report serves to illustrate the increased margin of safety usually found in a frame with restrained connections that has been designed by a rational method according to the theory of elasticity, and has been proportioned for stresses which, when multiplied by the assumed factor of safety, will not exceed the yield point value of the steel at any point. An analysis was made of four rigid frames to determine the real factors of safety for the columns which were bent in single curvature. In all the frames the true safety factor for the columns was found to be considerably in excess of 2, the factor that was assumed in proportioning them; and in one case the true factor of safety was 7.72.

In some rigid frame designs with which the writer is familiar, for which the columns were proportioned by the conventional method and at no increase in allowable stresses, considerably heavier columns have been provided for the rigid frame designs than those for alternate designs in which rather deep roof trusses were framed into the columns, introducing high moments that were disregarded in the conventional manner. Had the rigid frames been designed and their members proportioned by a method that revealed the true factor of safety, it would have been possible in some cases ro reduce the sizes of the columns rather than to increase them.

In view of the wide spread in true factors of safety in various kinds of conventionally designed, restrained and partially restrained frames with various relative stiffness of members and various actual degrees of rigidity of connections (even though they are assumed to be either flexible, or in some cases fully rigid), it is obvious that the proper approach to solving the problem is not through an arbitrary increase in working stresses, but rather through the development of a practical method of design that reflects the true behavior of a frame up to the point of collapse or failure. A program of the Welding Research Council at Lehigh University has been initiated which may lead to the perfection of such design methods.

Box-Girder Tests at the National Bureau of Standards

A series of six 9-ton, welded, structural carbon steel box girders of 22-ft. span, 2 ft., 6 in. over-all width and 2 ft., $1^1/_2$ in. over-all depth, are being constructed at the Ingalls Shipyard in Pascagoula, Miss., for static load testing at various temperatures in the Mechanics Section Laboratory of the National Bureau of Standards for the Structural Steel Committee of the Welding Research Council. Three girders have been built and tested thus far, yielding some very interesting information upon the behavior of constructional steels at various temperatures (Figs. 1, 6 and 10).

The purpose of the research program is to investigate, at various significant testing temperatures, the effect of severe geometrical constraint against ductile behavior upon the capacity of a welded structural member for resisting rupture under external load, when the constraint is caused by general shape and proportions and by the use of thick material ($1^1/_2$-in. tension flange fitted between side or web plates of the same thickness), without the deliberate introduction of a notch-effect of some kind. A further purpose is to observe whether there is any indication that the effects of residual stresses may be detrimental; although some other research as well as studies of experience records have led to quite a widespread belief now that residual stresses are not detrimental to a structure built of ordinary structural steel. Very abusive welding procedures and sequences are being used in the construction, along with some unfavorable details of design that afford severe restraint, with the thought of producing the highest possible locked-in stresses, especially in the vicinity of the transverse closing butt weld of the tension flange which is being welded last under extreme conditions of restraint.

A feature that has impressed bridge and structural engineers strongly is that the girders have been successfully proportioned to insure against failure by lateral deflection or buckling and twisting, as test beams and girders usually fail. To this end the compression flange was made $2^1/_2$ in. thick.

In Table 1 are given some of the characteristic results of the tests of the first three girders. The recently tested third girder, constructed of fully killed steel and tested at room temperature, was sustaining a load of 1685 kips, equally distributed between two load-points 2 ft., 6 in. on either side of mid-span, when the center deflection reached 18 in., with the bottom of the girder approaching contact with the supporting girders of the testing apparatus which had then reached their safe capacity (Fig. 1). The permanent center deflection after removal of the load was $16^1/_2$ in. The extreme fiber stress, computed under

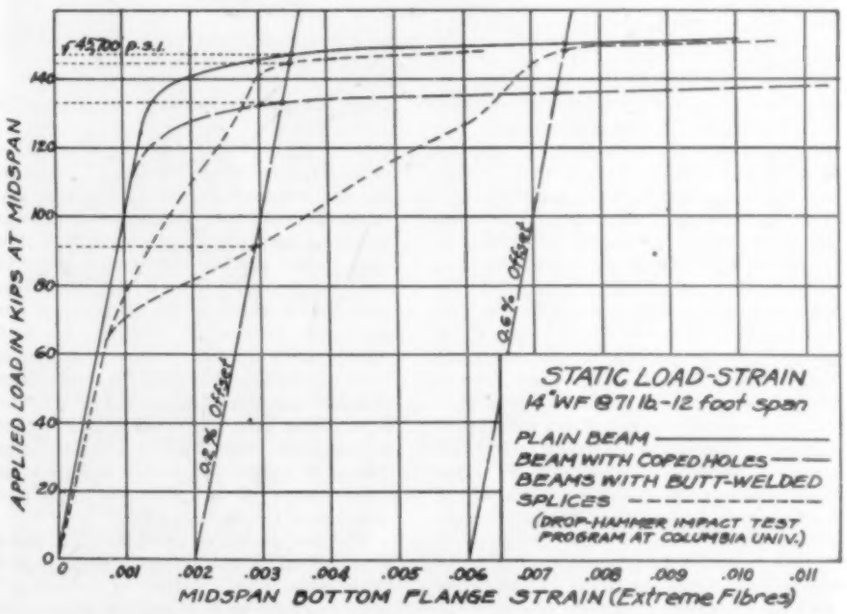


Fig. 9—The Effective Yield Strength of Steel Material in a Beam Is Considerably Higher Than the Yield Point Determined by Coupon Tests of the Material. Early Departures from Proportionality as Indicated by Extreme Fiber Strains Produced No Adverse Effects Upon the Structural Behavior of the Beams, Under Either Static Load or Impact

Table 1—Summary of Test Results of Box Girders Nos. 1, 2 and 3, National Bureau of Standards Program

	Girder No. 1	Girder No. 2	Girder No. 3
Kind of steel (all steel had approx. the tensile properties specified for A.S.T.M. A-7 Structural Steel)	Semikilled structural hull plate taken from stock	Fully killed steel of special order	Same heat as for Girder No. 2
Temperature of girder during test	+78° F.	−45° F.	+84° F.
Maximum load sustained (Kips)	1397	1165	1685
"Modulus of Rupture" (Kips per sq. in.):			
(*a*) Extreme fibers (side plates)	75.6	63.1	91.2
(*b*) Bottom of tension flange plate	58.2	48.5	70.2
Type of fracture	Brittle ripping,	Brittle, shattering	Did not fracture
Total max. deflection at mid-span	8 In.	(1000 Kip load) 1⅜ in.	(1685 Kip load) 18 in.
Total permanent deflection at mid-span	7 in.+	9/16 in.	16½ in.
Final permanent strains after test:	(2-in. gage length)		(4-in. gage length)
(*a*) In bottom edges of side plates	5%+	...	3.4 to 5.1%
(*b*) In tension flange between diaphragm and splice-weld	...	...	3.2 to 5.0%
(*c*) In tension flange plate at diaphragm	...	...	3.2 to 3.7%
(*d*) Across butt-weld splice in tension flange (between diaphragms)	...	...	2.3 to 2.5%
Per cent reduction in thickness of tension flange plate at fractured edge (local reduction)	0.7 to 1.8%	Less than 1%	Did not fracture
Charpy V-notch test values, average for bottom and side plates, as-rolled:			
(*a*) −40° F.	...	5.5 ft.-lb.	
(*b*) −20° F.	...	6.8 ft.-lb.	
(*c*) −10° F.	3.0 ft.-lb.	...	
(*d*) 0° F.	3.0 ft.-lb.	12 to 22 ft.-lb.	Material from same heat of steel as Girder No. 2
(*e*) +20° F.	3.5 ft.-lb.	9 to 56 ft.-lb.	
(*f*) +70° F.	12.0 ft.-lb.	33 to 68 ft.-lb.	
(*g*) +130° F.	42.0 ft.-lb.	68 to 96 ft.-lb.	

this loading, as for a modulus of rupture, was 91,200 psi. in the projections of the side plates and 70,200 psi. in the tension flange plate. In all of the tests, extensive electric strain gage readings were taken. The load required to deflect this third continued to increase up to a deflection of 17.93 in., virtually to the end of the test, although it increased at a greatly diminished rate after plastic yielding had become quite general in the middle portion of the girder. No indications of incipient fracture were observed, other than several small cracks on the bottom inside projecting edges of the side plates where permanent deformations as great as 5% occurred. There was comparatively little constraint at these projecting edges, which were reasonably smooth. Permanent deformations in the tension flange-plate ranged from 2.3 to 5%, depending upon local conditions of constraint and probably with some influence from the higher yield point of the weld metal.

A complete description of the specimens and of the program as originally visualized was reported in the *Welding Research Supplement* of the JOURNAL of the AMERICAN WELDING SOCIETY, in December 1944.

The first girder was constructed of ordinary, semikilled structural steel meeting the requirements for hull plating and taken from stock in the shipyard. It was tested in April 1945, somewhat as a pilot test, before placing the special order of steel for the other five girders, which was specified to meet the requirements of the American Bureau of Shipping for hull plating, with the further provision that it be fully killed steel, mainly for the purpose of insuring better uniformity, but with the expectation that this steel would exhibit a transition from high notch-toughness values to lower ones within a somewhat lower range of temperatures than the material of the first girder.

The first girder, of semikilled hull-plate steel, tested at room temperature, failed by rupture with a brittle or "cleavage" type fracture and a sudden release of energy that produced a loud report and shook the laboratory building; but failure did not occur until the measured strains and elastic deflection indicated extreme fiber stresses approximately equal to the conventionally determined ultimate tensile strength of the steel, not far below the modulus of rupture of 75.6 kips per square inch as computed for the breaking load of 1397 kips and corresponding bending moment of 71,200 kip-in. The fracture was propagated across the tension flange and up the side plates to the compression flange within a split second, its course being almost entirely within the base metal. The total deflection at the time of failure was about 8 in., of which a little less than 1 in. was elastic deflection, the remainder being permanent set. Plastic deformations measured at the point where fracture started, at a rather small flaw or imperfection in one of the transverse welds, were well below 1% reflecting the constraint that had been imposed upon ductile behavior and had prevented much localized absorption of energy and redistribution of stress in the region of the fracture.

The second girder, of fully killed steel, from the same heat as the third girder, was tested at about −45° F. As was to be expected from the notch-toughness of the material at this low temperature, as determined by auxiliary tests of small specimens at various temperatures, this girder failed likewise with a brittle or cleavage type of fracture. The notch-toughness of the material was greatly reduced by the low temperature. In this case, however, the fracture was more of a compound, shattering type, under the influence of the cold temperature, and the entire girder snapped in two. The breaking load of 1165 kips was, however, only 16.5% lower than that of the first girder, although it was about 31% lower than the maximum load imposed upon the third girder which was constructed of the same fully killed steel but tested at room temperature. The test of the third girder had to be discontinued before rupture occurred, although the deflection was so great (Fig. 1) that the result of further loading would have been of no practical significance. Toward the end of the test, the continued deflection was probably due very largely to shearing detrusion.

The deflection of the second girder could not be measured accurately during advanced stages of the loading because of the failure of the apparatus that was set up for taking deflection measurements within the enclosure for the dry ice and cold atmosphere surrounding the girder. However, quite complete strain gage measurements were obtained. From such data as were taken, the total deflection of this girder was computed by indirect methods and was believed to be only about 1.38 in. at a load of 1000 kips, of which some 0.56 in. was permanent set.

The heavy, closely spaced transverse diaphragms of these box-girder specimens were intended to provide transverse restraint simulating that in the plating of a transversely framed ship, resulting from the lateral resistance of the frames and deck beams. Permanent sets, measured after the conclusion of the test of the third girder, were somewhat less in the vicinity of these diaphragms, reflecting their restraining effect; but the permanent sets at gage points on the transverse butt welds (both those backed up by diaphragms and those between diaphragms)

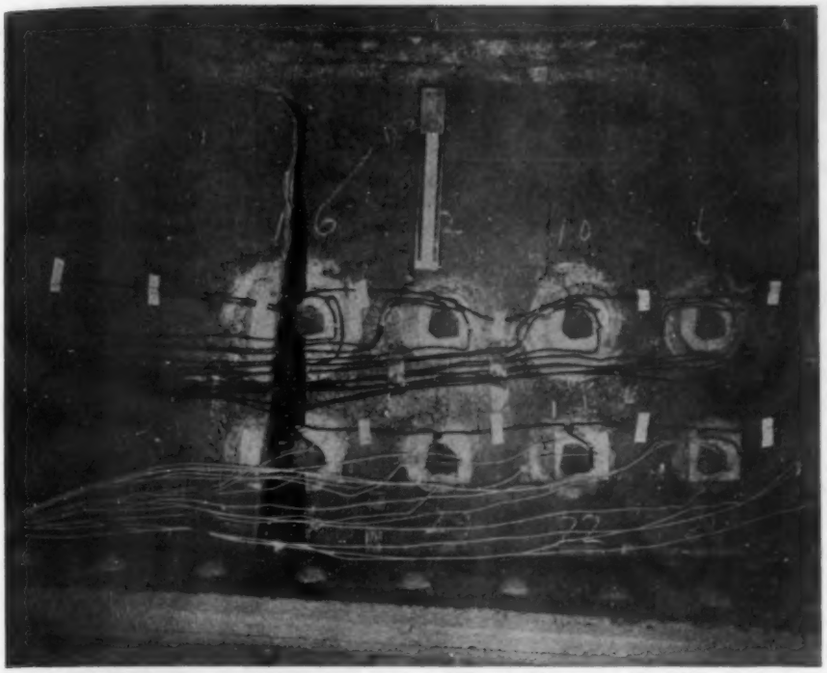


Fig. 10 (*a*)—Fracture of Box Girder No. 1, Constructed of Semikilled Structural Hull-Plate Steel and Tested at Room Temperature

were considerably less, running quite generally as low as 2.3%, as compared with sets of 5% measured at some parts of the tension flange.

Even a narrow, flat bar with free edges will neck on both sides of a transverse butt weld rather than at the weld when the bar is tested in tension. Since the residual stresses in a butt weld across a narrow bar are comparatively small, this behavior does not appear to be the result of residual stress. Perhaps it is the result of the considerably higher yield strength of the weld metal, with some influence from the slightly increased thickness at the weld.

There was no apparent evidence in the behavior of these box girders of internal locked-up stress over a wide area, such as the so-called "reaction stresses" that were intended to be set up by the abusive welding procedure and sequence that were imposed in the construction. No residual stress measurements have been made yet, but if such wide-spread reaction stresses exist, they do not seem to influence the behavior of the girder or the strains as measured during and after loading. The temporary effects of residual stress that were manifested during the testing were all localized and apparently exerted no unfavorable influence upon the girder.

At the beginning of the war production program in shipbuilding, a good many engineers still believed that residual stresses might be a very unfavorable factor influencing the behavior of structures built of mild or structural carbon grades of steel. A great deal of research concurrent with and preceding the box-girder tests of the Welding Research Council, as well as studies of experience records made in this country and in foreign countries, has led to quite a general belief now that residual stresses were not a factor of any importance in the cracks that have occurred in the hulls of some ships. It is known that ships that have exhibited remarkably good behavior under very adverse circumstances must have contained residual stresses as large as those in ships that have fractured. Also, since stress concentration factors of notch-effects in ships' structures have been found to be as high as 10, and since these concentrations are not reduced as much by plastic deformation, nor as readily as residual weld-stress peaks are reduced, residual stresses of even yield point intensity appear small by comparison. It seems reasonable to believe, therefore, that the benefits of following proper welding sequences and fitting practices, which have been conclusively demonstrated in practical experience, are principally in the form of assurance of sound welds and avoiding such severe restraint against weld shrinkage as might cause local cracking during construction, or cause objectionable distortion.

Fig. 10 (*b*)—Shattering Type of Fracture of Box Girder No. 2, Constructed of Fully Killed Structural Steel (Same as the Steel for Girder No. 3), But Tested at —45° F.

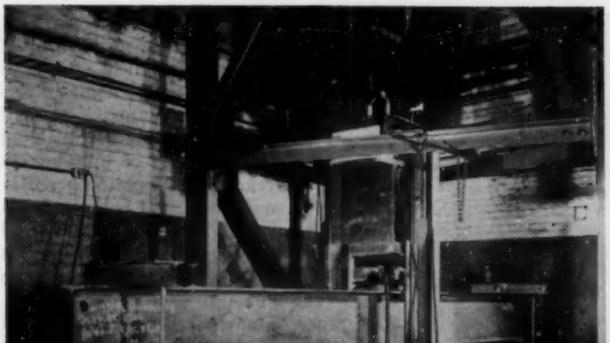


Fig. 11—Equipment at Columbia University for Drop-Hammer Flexural Impact Tests of Steel Beams with Butt-Welded Splices at Mid-Span

Fig. 12—Specimen After Testing Under Repeated Drop-Hammer Blows at Columbia University

Drop-Hammer Flexural Impact Tests of Rolled Beams with Butt-Welded Splices

A program of drop-hammer, flexural, impact tests of rolled beams with butt-welded splices was initiated shortly before the war at the Civil Engineering Testing Laboratories of Columbia University, with the original objective of determining for the bridge specifications committee of the AMERICAN WELDING SOCIETY whether residual stresses due to welding could combine with load stresses to cause failure, if the load were introduced so rapidly that there might not be time for stress peaks to be ironed out by the occurrence of plastic deformations, as they are under static loading. However, the investigation was carefully conducted by the laboratory staff, and instantaneous values of strains and deflections were accurately measured so that the investigation would be of value as a fundamental study of behavior under impact. A great deal of very valuable fundamental data and information has therefore been developed.

When none of the beams tested at room temperature fractured, but merely crumpled under the continued pounding from the hammer (Fig. 12), it became evident that the residual stresses had not reduced the resisting capacity of the beams. Rates of deformation of nearly 1 in. per inch, per second, had been measured, which are surely much greater than would be expected in any highway or railway bridge. It was then decided to make some pilot tests of similar beams at temperatures of about −40° F., in preparation for an extended program to investigate the effect of various testing temperatures upon beams constructed of two kinds of structural steel, one with generally better notch-toughness properties than the other. It is hoped that this program, along with the one at the National Bureau of Standards, will yield some valuable information upon "size-effect" and permit a better correlation between the results of small control-test specimens and the behavior of full-size structural members, so that the minimum notch-toughness value of the material that is desirable for constructional steels may be determined, with proper regard for their service conditions such as temperature of service and kind of loading.

The testing apparatus is illustrated in Fig. 11. The 1000-lb. tup in vertical guides is released from an electromagnet. It strikes a steel block which straddles the top-flange splice-weld producing virtually a concentrated load at mid-span. The static tests of control specimens are also made with the load concentrated at mid-span.

The specimens are 16-in., 71-lb., wide-flange beams of 12-ft. span, with hinged ends tied down to prevent rebound. Some plain rolled beams have been tested, as well as the beams with butt-welded splices in both flanges and web at the mid-span point. As evident in Fig. 12, semicircular holes were coped in the webs of the welded beams, adjacent to the flange welds, to provide access for sound welding, and these holes were left unfilled. The beams have been tested in the "as-welded" condition.

For some of the beams tested at room temperature the height of drop of the tup was gradually increased until crippling occurred. One beam was tested with an initial drop of 5 ft., 6 in. (V = 18.8 ft./sec.) which was then increased to a 10-ft. drop (V = 25½ ft./sec.). Another was tested under an initial drop of 7 ft., 6 in. (V = 22 ft./sec.) and the load repeated until the beam crippled.

In view of the fact that impact-test results are usually measured and reported in units of energy, because it can be measured conveniently in Charpy or Izod notch-bar tests, it should be emphasized that strains and deflections within the range of elastic behavior are approximately proportional to velocity rather than the square of the velocity or the energy. This is sometimes overlooked in making comparisons of impact tests.

Approximate stresses were computed upon the assumption that the difference between the total dynamic strain increment (occurring during an impact blow) and the permanent increment of strain for the same blow, represents an elastic strain which can be properly translated into a stress value. This indicated a stress of 72,000 psi. during the first few hammer blows from a height of 7½ ft. The stress computed in the same general manner from the dynamic and permanent deflections was about 60,000 psi., which, of course, does not include the stress from the inertia effect of the beam, which seems to account for the lesser stress value as compared with the 72,000 psi. Some of the simultaneous records of strains and deflections shown that strains develop in the bottom flanges of the beams directly under the load at mid-span before any deflection of the beam has been produced.

Departure from proportionality of strains and deflections to loads (in the case of static tests) and to velocities of load application (in the case of drop-hammer tests) occurred at quite low loads or velocities for all the beams with welded splices tested at room temperature, in fact, at values only about one-half those that caused initial indications of plastic deformation in the tests of plain beams. This effect, which was most pronounced in the static load tests, was to be expected, because similar small plastic deformations have been observed many times in previous tests of welded beams, as residual stress-peaks become ironed out. As in other tests, there were no indications that the early departure from proportionality affects the resistance of a beam to withstand loads, whether they be static or impact loads. In fact, in some tests of beams under static loading at the University of Illinois, a higher yield strength, as determined from observations, was reported for the welded beams than for plain rolled beams.

There had been some conjecture as to whether the semicircular copes in the webs adjacent to the flanges (which were introduced to facilitate welding from both sides of the flange splice welds) might cause sufficient stress concentrations to affect the behavior of the beam adversely under impact. On the other hand, there

was the possibility that they might be beneficial in reducing multidirectional local constraint at the junction of the web-splice and flange-splice welds (of comparatively high yield-point metal). To investigate the effect of the copes, one welded beam was tested under static load without such open coped holes, and one plain beam was tested with similar copes in its web, introduced after the beam had first been loaded to the point where a very slight amount of plastic deformation had taken place. No adverse effect of the coped holes was observed when the strains and deflections were plotted.

One of the beams tested under impact at room temperature had quite a defective bottom flange splice weld due to an improper welding procedure that was used. Under the first few blows of the hammer, a crack developed where the penetration was especially deficient, opposite the web on the center line of the flange. However, the crack was not propagated by further impact blows, and the beam failed by crippling, thus apparently reflecting the beneficial effect of the higher notch-toughness at room temperature that had been determined by the auxiliary tests, as compared with lower room-temperature notch-toughness such as that of the material for the first box girder tested at the National Bureau of Standards at room temperature (Fig. 10)

Four beams were tested under impact at a temperature of −40° F. or lower: two plain beams, one welded beam with a reasonably sound tension flange weld and one welded beam with a defective tension flange weld.

The first beam tested at the cold temperature, one with a good welded splice, broke in two under the first impact blow, delivered from a height of 90 in. The fracture was almost entirely of the brittle or cleavage type, with only a very small area of fibrous or ductile type at the point where fracture appeared to have started, in the tension flange at the edge of the semicircular cope in the web, well in the clear of the tension flange butt weld. There also appeared to be a very narrow band of fibrous fracture along each edge of the fractured face of the web. The location of the fracture in the bottom flange created some doubt again regarding the effect of the coped holes as geometrical stress raisers. However, the second beam that was tested at cold temperature, one with a defective butt weld, withstood an impact blow delivered from a 66-in. height and one from a 90-in. height and finally failed under the second blow delivered from a height of 120 in., fracturing through the defective butt weld in the tension flange and along a very irregular path in the web, almost entirely in the base metal, and through the defective compression flange weld, after this beam had withstood a substantially greater impact than the first beam. To further investigate the effect of the coped holes in the web, similar copes were made at mid-span in a plain beam and it was tested at low temperature. It withstood several impact blows from heights of 90 and 120 in. without fracture, the 120-in. drop being the maximum possible for the testing apparatus. The plain beam without coped holes had withstood similar impact blows without fracture.

Since it was impossible to test the plain beams to failure by fracture, their capacity is unknown. The difference between the stresses or striking velocities for the 90- and 120-in. hammer drops is not very much; so no great difference in performance for the two welded beams is conclusively established. Also, the beams furnished for the program were not all from the same heat, and they varied somewhat in their characteristics. For example, at least one of the beams tested at room temperature seemed to be particularly susceptible to strain-age hardening as revealed by the curves plotted for strains and deflections against the velocity of hammer drop for this beam, for which the drop-hammer impact test had to be interrupted for a period of three months.

Further auxiliary tests of the materials may throw some light upon the matter, but definite conclusions cannot be drawn from such a small number of specimens as were tested. However, it seems rather apparent that the geometrical stress-raiser effect of the coped holes cannot be very serious under usual circumstances. Until further tests have been made one is led to believe that the material of the first beam tested at cold temperature was particularly susceptible to loss of notch-toughness in the zone affected by the heat of the welding. Other research has indicated that some steel materials are affected in such a manner, but that the weld metal itself is of better notch-toughness than structural steel in the as-rolled condition. There is quite a bit of evidence that steels which are susceptible to such a loss of notch-toughness in the zone affected by the heat of welding are also susceptible to strain-age embrittlement. In this case, it does not seem that any severe cold-working could be involved. DeGarmo of the University of California found that in an automatically welded butt joint of 20-in. length, the maximum plastic strain occurring during cooling had an effect upon the tensile properties of the weld metal no greater than that of a $^1/_2$% plastic strain at room temperature. It is difficult to conceive of the plastic strains in the adjacent base metal being greater than a fraction of a per cent. However, some metallurgists believe that such a condition could result in strain aging in some of the carbon structural steel material that is encountered occasionally.

Experience and research in general, as well as the auxiliary tests of material taken from beams tested in the earlier part of the program, lead to the belief that the low-temperature notch-toughness of all the beams of this program was little better, if any, than that for the first girder of the program at the National Bureau of Standards, although the room-temperature notch-toughness was much better. Also, the data from the drop-hammer tests of beams at low temperature showed only very slight amounts of permanent set for strains and deflections, the yield strength of the material having been raised by the effect of the cold temperature, virtually up to the fracture strength.

In cooperation with the Welding Research Council and the laboratories at Columbia University and at the National Bureau of Standards, the Naval Research Laboratory at Washington, D. C., is carrying out the very valuable auxiliary tests that have been mentioned for determining notch-toughness values of the materials, for use in determining the size-effect or correlation between behavior of small specimens and that of the full-size structural members. Fig. 4(b) represents one type of auxiliary test data being developed.

Behaviour of Steel Materials Subjected to Repeated Stress

Very little seems to be known about the effect upon fatigue strength that results from a few previous applications of overstress sufficient to cause small plastic deformations, such as those that almost invariably occur in any structural member as the stresses in it are becoming redistributed while the structure adjusts itself to service loads and conditions, and such as those plastic deformations that are recognized in elasto-plastic theories of design. We do know that for pulsating direct stress and a comparatively small range of stress, say from three-fourths maximum to maximum tension, the fatigue strength is usually well above the yield point. Quite an appreciable permanent set must occur in such a case upon the first application of the maximum stress.

The mechanism of the fatigue behavior of steel is not too well understood, in general. The material seems to undergo some kind of highly localized, progressive damage along slip lines, under repetitions of stress (if stress and range of stress are great enough) until a fracture starts. This damage apparently is not repaired by heat treatment or by rest periods, but, strange as it may seem, may be healed by quite a large number of cycles of understress (which are likely to occur in many of our practical engineering structures following any overstress). Some tests have shown an actual increase in endurance limit as a result of progressively increasing cyclic understress, even after many cycles of overstress.*

There is quite a bit of evidence that at least under some circumstances plastic deformation can increase fatigue resistance, whether it is by reason of the work-hardening that takes place or by reason of compression prestress set up at propitious locations, for example, in the case of "shot-blasting" to increase fatigue resistance. Tests have already shown that comparatively few repetitions of overstress (which were above the endurance limit but below the yield point in these tests) may actually increase the endurance limit somewhat. It has been suggested that overstress which sets up residual tension stress in extreme fibers is damaging, but that which sets up residual compression stress, or which diminishes residual tension stress, improves fatigue.

In the fatigue testing of welded structural connections at the University of Illinois for the Welding Research Council no effect of residual stresses has been observed, and although some other investigators have believed that they have de-

* See various technical reports and paper by J. B. Kommers in *Proceedings of Am. Soc Testing Materials*, 1938, 1943 and 1945.

tected comparatively small effects of residual stresses, it is commonly believed that under most circumstances residual stresses are largely ironed out by the first few applications of stress and thereafter they have no effect upon the behavior. Small plastic deformations are required to effect such a redistribution of stress, whatever may have been the cause of the oringinal nonuniform stress distribution; and the stress-peaks are reduced at the points of stress concentration where fatigue failure tends to start.

Although the tests that have reflected the influence of cyclic overstress and understress (mentioned herein before) involved notched bars as well as smooth bars, any structural member is considerably more complex than the small specimens that have been used for such fundamental investigations of fatigue behavior. It may well be that in a structural member, the net effect of some plastic deformation can be beneficial to fatigue resistance if in no other way than by reason of the reduction of stress peaks. If such deformations are restricted in some way, by constraint or by a lack of ductility in the material, fatigue failure might occur more readily at points of stress concentration. It has been shown that steels of higher strength and lower ductility are generally more sensitive to damage from overstress (beyond their normal or virgin endurance limit). This suggests that the effective ductility of a steel under the prevailing conditions of constraint in a structure, might be a factor in fatigue strength, although it should be emphasized that tests of small specimens have shown no correlation whatsoever between notch-sensitivity under repeated stress and notch-sensitivity as indicated by a notched-bar impact test, at various temperatures of testing.

There seems to be an almost complete lack of any fundamental information to bridge the gap between data gained from the testing of small specimens and the fatigue data, of a more practical nature, that has been developed thus far by the Welding Research Council to meet a rather urgent need for a basis of establishing unit working stresses in design. With the hope of bridging this gap, a new fatigue testing center has been established by the Fatigue Testing (Structural) Committee of the Council, at the University of California. Tests of welded structural members and connections are being continued at the University of Illinois, in so far as the available equipment assigned to such work will permit, but most of their facilities have now been allocated to other work.

Although it is certain that quite appreciable permanent deformations occur in any structure, riveted steel, welded steel, concrete or timber, whether the designer recognizes them or not, practical designers will not likely take such deformations into account in the design of dynamically loaded welded structures and rely upon help through plastic deformation in such cases, until more fundamental information is made available through fatigue tests of structural members and connections.

After such further fundamental information as seems to be urgently needed has been developed, it is expected that the fatigue program at the University of California will be devoted to an intensive study of the effect upon fatigue resistance of various practical details of design for welded structures.

Design of Members and Connections for Fatigue

A great deal of very valuable information and data has already been developed for the practical design of members and connections subjected to fatigue loading in the programs of the Fatigue Testing Committee of the Welding Research Council at the University of Illinois. Use of this information has been made in developing allowable unit stress provisions for the bridge specifications of the AMERICAN WELDING SOCIETY and, to some extent, in establishing provisions for the most favorable details of design.

This investigation has also served to emphasize the tremendously better fatigue value of a good butt-welded joint than any kind of joint involving the use of overlapped material.

The main guiding principle that governs in the choosing of details of design is to avoid notch-like details or abrupt changes in section that would kink stress-paths, and to provide for the most uniform distribution of stress that can be achieved in a practical manner, in the base metal as well as in the connection material. For example, in a fillet-welded end connection for an axially stressed member, a combination of transverse and longitudinal fillet welds (and perhaps fillet welds in holes, in the case of a very wide member) seems to accomplish the most uniform distribution of stress and result in the best fatigue resistance. Results of fatigue tests, in general, have shown that fatigue resistance is increased very substantially by carrying fillet welds continuously around the corners of the connected material. Although this beneficial effect may not be very evident in cases where a critical section for fatigue failure does not exist at the point where the weld returns are located, it is a good general rule to provide them in details such as the one that is illustrated in Fig. 13.

The size of the fillet welds and the shape of the transverse end-fillets is likewise important. Elongated transverse fillet welds, Fig. 13, have long been recognized as beneficial in reducing stress concentrations at the toes of the welds, under static loading as well as fatigue. Grinding the toes of the fillets and tapering the connected material in thickness provides a still further increase, but such expensive procedures are not usually justified for the connections of bridge members. Fillet welds can be deposited in an elongated shape, however, by practical welding procedures.

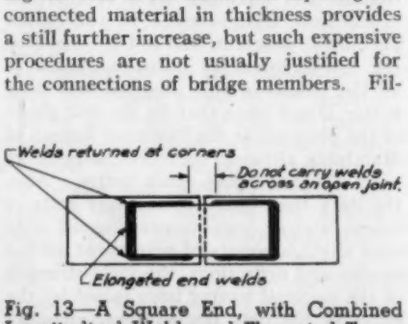


Fig. 13—A Square End, with Combined Longitudinal Welds and Elongated Transverse Welds, Provides the Best Practical Detail for Fatigue Resistance, for a Fillet-Welded End-Connection or the End of a Partial Length Cover Plate

If the length of the longitudinal fillet weld segments at the end of a partial length cover plate of a beam, or at the end of an end-connection of an axially stressed member, is much less than the width of the connected element, or if the welds are of inadequate size in proportion to the thickness of the material (even though the amount of welding as a whole seems to satisfy weld-stress requirements), the stress distribution in the base metal is affected adversely and the fatigue strength at the critical section in the base metal is reduced substantially, especially if end transverse welds of adequate size cannot be provided for some reason, and the longitudinal welds must be used alone.

The choosing of adequate weld sizes and arrangements of welds so as to provide a transfer of stress in a manner that will be less detrimental to the fatigue strength of the base metal will be illustrated by a comparison that appears to substantiate the contention mentioned in the preceding paragraph. In the specimens of Series GB of Fig. 14, the end transverse fillet welds were made $^1/_4$-in. size, the minimum size permitted by structural specifications for deposition on $^3/_4$-in. material (the thickness of the end connection plates). The interior transverse fillet welds, at the most critical section for fatigue failure were made only $^1/_8$-in. size, in violation of the specifications on two counts. The web thickness of the channel was only $^1/_4$ in. but the end plates were $^3/_4$ in. thick. Further, the minimum weld size permitted under any circumstances is $^3/_{16}$ in. Preliminary tests had shown that even this $^1/_8$-in. size, interior, transverse weld increased the fatigue strength slightly. Despite the small size of this interior transverse weld, the fatigue strength of this series, stressed from 0 to max. tension, averaged 21.7 kips per square inch for 100,000 cycles and 11.8 for 2 million cycles, slightly higher than for a similar member with riveted connections which had a 12-in. overlap of material as compared with 6 in. for the longitudinal welds of Series GB.

For the specimens of Series 43-2 of Fig. 14, the size of the end transverse welds, also, was reduced to $^1/_8$ in. (further violating the specifications), and the size of the longitudinal side welds was reduced to $^5/_{16}$ in. Failure still occurred in the base metal. The fatigue strength of these connections for 100,000 cycles and 2 million cycles was only 16.7 kips per square inch and 9.1 kips per square inch, respectively. The fatigue strength of the GB Series was thus shown to be 30% higher.*

There is a very unfavorable kinking of stress paths that is inherent to any kind of joint made in overlapped material, in the transfer of stresses from one plate or element into another one in a different plane. Also, it is difficult to devise practical details for fillet-welded end-connections of axially stressed members in such a manner as to avoid re-entrant corners and the

* This increase is about 35 to 40%, without including the results of GB Specimens that failed at batten-plate connections before their details were improved, which, however, leaves only one specimen.

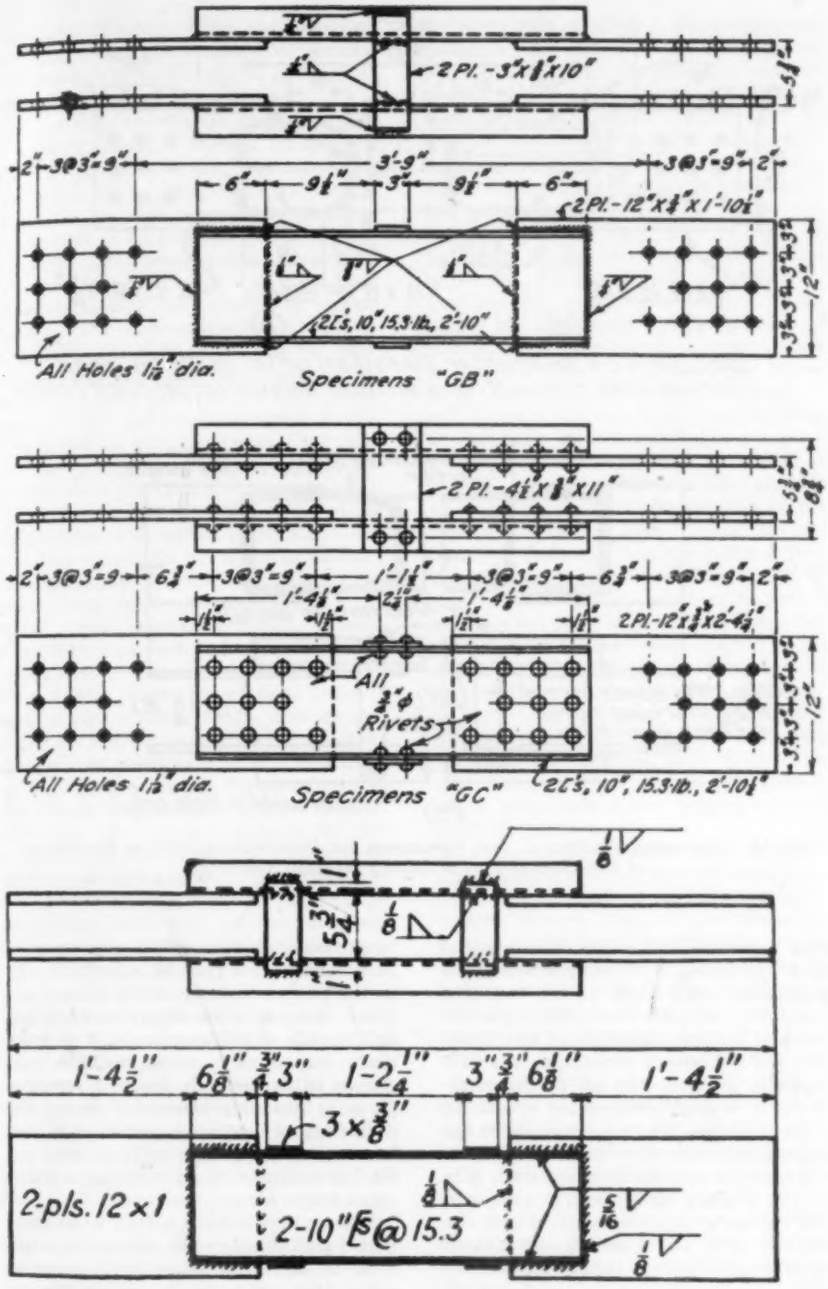


Fig. 14—Specimens Tested to Determine the Fatigue Resistance of End-Connections of Two-Plane Axially Stressed Members Such as Those of a Heavy Truss

effect of them that is illustrated in sketch (e) of Fig. 2.

For the end-connections of an axially stressed, wide-flange rolled section, such as those commonly used for truss members of bridges, the details of Fig. 15 (*a*, *b*) are suggested as an arrangement that would seem to offer better fatigue resistance than some of the details that have been tested. They are believed by the writer to offer the further advantages of the continuous, transverse stiffening contributed by the web of the section, across the critical section for fatigue failure, to reduce secondary bending stresses which have appeared to be somewhat detrimental in some of the connections that have been tested. When two-plane members are composed of two channels that must be provided with batten plates, the details of Fig. 15 (*c*) would appear to offer a practical means of connecting the batten plates in such a manner as to result in a minimum of adverse influence upon the fatigue resistance of the channels, judging by the record of the performance of such a detail in other applications. It is hoped that the details of Fig. 15 can be investigated in fatigue tests.

In any arrangement of partial length cover plates for a beam or girder, there appears to be an inevitable sudden surge or transfer of a considerable amount of horizontal shearing stress at the end of the cover plate, which is not accounted for in an integration of the shear that is transferred from a beam to a cover plate, according to the conventionally used formula, $H = VQ/I$. Therefore, fatigue tests of beams with either welded or riveted partial length cover plates show surprisingly low values.

In one riveted specimen that was tested, failure occurred near mid-span rather than through the rivet holes in the beam at the end of the cover plate, suggesting that the fatigue strength of a beam with full-length riveted cover plates would be much less than developed by test specimens with full-length welded cover plates. If very unsuitable details for partial-length welded cover plates are used, the fatigue strength of the reinforced beam is substantially less than that of the riveted beam that was tested, especially for larger numbers of repetitions of stress such as 2 million cycles.

Although a good many of the details for partial-length welded cover plates that have been tested did not show very great differences in fatigue strength, the test results have shown that by choosing suitable (and entirely practical) details and arrangement of welding, it is possible to increase fatigue resistance at 2 million cycles of stress (ranging from 0 to max. tension) more than 50% and probably as much as 75%, as compared with the most unfavorable details tested, which were so unfavorable that even under static load the unit stress at failure was only 66% of the value for the welded beams with good details. However, this value for the welded beams of most unfavorable details was still 90% of the value for the plain rolled beams. In all the static load tests of the beams of this program, failure occurred by buckling of the compression flange.

By means of special expedients such as tapering in thickness of end of cover plate and grinding the toes of end fillet welds, the increase effected in fatigue strength over the most unfavorable details is as much as 87½%, and a 100% increase seems possible. However, it would be less expensive to extend the termination of the cover plate to a region of lower stress, in most cases of structures in which saving of dead load weight is not of paramount importance.

Aside from the effect of size and shape of end transverse welds, and that of size and length of end portions of longitudinal welds, which have already been discussed, there are several other factors of importance that seem to affect fatigue strength at the end of a cover plate. One of the most important of these is the re-entrant corner notch-effect that is introduced when a partial-length cover plate is made wider than the beam flange, which proved to be one of the most unfavorable details that have been tested. Clipping the corners of the ends of the cover plates on an angle of 45° does not seem to mitigate the notch effect much; at least it does not when weld returns are omitted. In this case weld returns, if used, would have to be carried across the faying surface in the direction of the thickness of the material, calling for special care to avoid undercutting (which, however, could be detected easily by visual inspection and remedied).

Other research has indicated that the

sharpness of a notch at its root is much more influential upon its stress concentration factor than comparatively large differences in the included angle of its general shape, for example, the difference between 45 and 90°. Depth of notch is also important.

In recent research, it has been found that fillet welds usually have to be reduced in size a great deal below what would appear to be balanced design requirements to make them fail in fatigue, and moderate reductions in size may just increase the stress concentrations somewhat in the base metal, where failure still takes place.

Another factor is the distribution of stress in the flange of a beam in a transverse direction. Contrary to quite a widespread belief that has existed for a long time, nothing seems to be gained by tapering the width of a partial-length cover plate down to a pointed end. In doing this, designers have presumed that the best expedient for minimizing stress concentrations would be to increase the cross-sectional area of the cover plate gradually, as stress is transferred to it by longitudinal welds. This seems to be fallacious reasoning. There are concentrations of stress at the end of any longitudinal fillet weld. When a cover plate is tapered in width, virtually to a point, two such regions of stress concentration are brought together.

The surge of stress at the end of any partial length cover plate, which has already been mentioned, and also the lesser flexibility of the flange of a beam along its center line opposite the web, as compared with the edges of the flange, may account for the fact that the tapering of a cover plate in width does not increase the fatigue strength of a beam, at the end of the cover plate, and may, in fact, decrease it. The mid-width region of the flange seems to be a poorly chosen region for concentrating the first pickup of stress by the cover plate.

The best practical arrangement for the end of a cover plate or of a connection plate for an axially stressed member, seems to be a square end with a fillet weld entirely across it, of adequate size and deposited in an elongated shape, which distributes the stress as uniformly as possible in a transverse direction, and avoids sharp kinking of stress paths, in so far as possible for a lap joint. Fatigue tests of connection plates provided with only transverse welds of good shape and adequate size, and no longitudinal welds, have shown fatigue strengths about as great as any fillet welded connections of plates that have been tested in the program at the University of Illinois. However, in view of the fact that many of the other specimens tested did not seem to have the most favorably proportioned transverse fillet welds when these were used in combinations with longitudinal welds, the writer believes that it is surely best to continue the transverse welds on around the corners at their ends, into longitudinal weld segments of substantial size and length, as previously described herein.

A comparison of the fatigue strengths of beam-specimens with partial-length cover plates, similar in all respects with the exception of the size and arrangement of fillet welds, leads to the belief that even

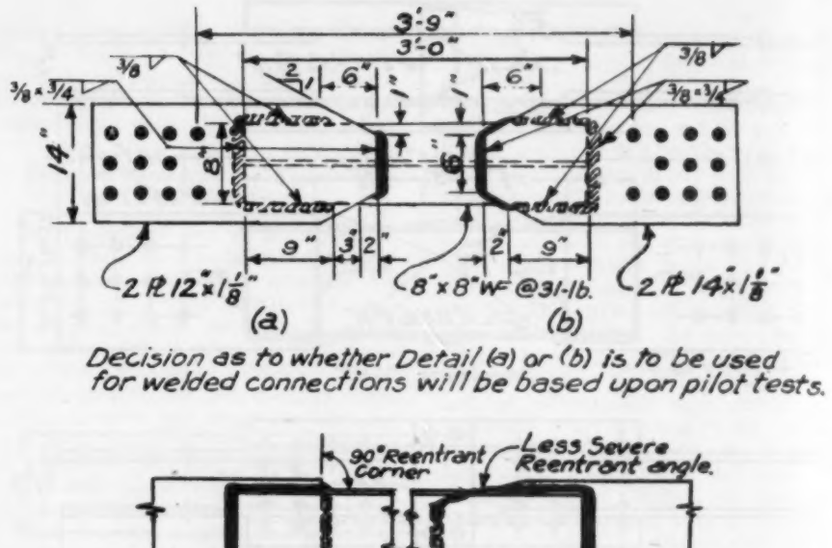


Fig. 15—Suggested Additional Test Specimens for Determining Fatigue Resistance of End-Connections of Axially Stressed Members

when transverse end welds of substantial size are provided, if the end portions of the longitudinal fillet welds at the end of a cover plate are quite short, the stress distribution is made considerably less favorable, and the fatigue strength is very substantially lowered. In all of the intermittently welded cover-plated specimens of the program, the end segments of the longitudinal welds were made of the same length as the intermediate segments, only $2^3/_4$ in., which is quite short, as compared with the width of cover plate, which was either 6 or 4 in. Continuously welded partial-length cover plates showed up better. Failure occurred at the end of the cover plate in all cases, even for the intermittently welded ones.

Beams with continuously welded full-length cover plates had an average fatigue strength 74% higher (at 2 million cycles of 0 to max. tension) than the specimens with riveted cover plates (rivet holes drilled) or the best beams with welded partial-length cover plates that have been constructed and tested thus far, without employing special, rather expensive shaping at ends of the plates. Specimens with full-length, intermittently welded cover plates were only 39% higher in fatigue strength than the riveted beams.

Since rather high-stress concentrations due to interruptions of stress paths exist at the ends of any longitudinal weld or weld segment carrying substantial stress, continuous fillet welds have long been recognized as providing better fatigue resistance than intermittent fillet welds, unless there are more serious stress concentrations elsewhere, as at the end of a partial length cover plate, in which case the use of continuous welds may be important only in the general vicinity of the critical section. Because of the stress concentrations at the ends of weld segments, it is especially important to avoid unfilled weld craters in dynamically loaded structures. Even in changing electrodes during the depositing of continuous welds, it is best to use a technique that will not leave unfilled craters of such a nature that a crater check might form.

When the width of a part is so great that longitudinal welds along its edges must be supplemented by welds made in holes, fillet welds made around the periphery of a hole or slot apparently offer better fatigue resistance for the member as a whole than plug or slot welds, which are made by filling a hole partially or completely with weld metal deposited in uniform thickness over the entire area of the hole.

When comparatively small attachments are made to a member, in pairs, on opposite sides of the member, the results of fatigue tests indicate a very decided advantage for staggering the attachments rather than matching them opposite to each other. For this reason, some girders have been designed with staggered web stiffeners. However, when transverse diaphragms are connected to stiffeners, and in their capacity as equalizers to distribute loads they are stressed in bending, it seems obvious that such connections on opposite sides of a girder might produce severe repeated bending stresses in the girder web if the stiffeners are staggered. Such repetitions of local bending in

the plating of tanker ships, at unattached bracketless ends of longitudinal girders, have resulted in fatigue cracks in the plating, around the ends of the girders.

At one time, the effect of transverse lines of welding across a tension member or element was rather widely believed to be invariably more detrimental to fatigue resistance than the stress concentrations at the ends of longitudinal welds. Upon this assumption, some bridge girders have been detailed with small steel-plate pads under the ends of the stiffeners on tension flanges. The transverse welding has been confined to the welds attaching the stiffener to the pad, and only longitudinal welds have been provided for the attachment of the pad to the tension flange. This prefernce may have originated from the test results of specimens with undercutting along the toes of transverse welds (a defect that is easily detected by visual examination and easily corrected). Recent test results do not seem to indicate any consistent or marked superiority for attachments made with longitudinal welds rather than transverse welds. Transverse welds now seem to be very definitely superior for an actual transfer of stress at a lap joint. Some fatigue tests indicate that comparatively short attachments which do not transfer stress from other elements or members do not introduce very large geometrical stress-concentration effects, as compared with the attachment of a cover plate on a beam, or with an end connection plate that transfers the entire stress of a member. Perhaps slight permanent deformations take place in the connecting welds and prevent short attachments from picking up much stress.

Since the welding of a stiffener to a flange constitutes an attachment that is very short in the direction of main stress, and it is welded to only one side of the flange, the stress concentrations arising from the kinking of stress paths would seem to be comparatively small. However, the results of some tests suggest that any stiffener fitted tightly against a tension flange, whether it is welded to the flange or unattached, causes stress concentrations in the general vicinity of its bearing, possibly due to secondary bending stresses induced in the flange. For this reason, and also to prevent an accumulation of débris in corners at stiffeners (which might retain moisture and cause corrosion), the ends of intermediate, non-load-bearing stiffeners have sometimes been cut a little short of tension flanges.

In detailing dynamically loaded structures, especially, it is advisable to provide ample edge distance for the depositing of fillet welds, for example, in choosing the width of a cover plate or the width of a stiffener that is to be welded to the flange of a beam (Fig. 16). If the margin allowed along the edge is only slightly greater than the weld size, the outer edge is likely to become scarred or scalloped where the size of weld overruns. Since the operator must maintain a minimum size of weld equal to that specified, and it is impossible to avoid slight variations in the size as deposited, occasional small overruns in size are unavoidable.

One of the most interesting, and rather surprising, results of fatigue tests of beams with partial-length cover plates has been the occurrence of failure in the compression flange, at the end of a top cover plate, when the bottom cover plate has been extended further to terminate at a point of lower stress. Although fatigue tests in general have demonstrated a considerably higher fatigue strength for compression elements, these compression flange failures have occurred at approximately the same stress as that for failures at the ends of tension flange cover plates of similar shape and weld arrangement. One possible explanation is that under highly localized stress a slight amount of plastic upsetting or compressive set occurs in the base metal at the toe of the transverse fillet weld, as well as in the weld, itself, which would result in a tension stress at that point after the loading is removed. Under such circumstances a reversal of stress (but with no change in total amount of range) could occur during each of the following cycles of load application and release. Unfortunately, the fractured portions of the beams that were tested in this program were not removed to permit examination that would reveal the exact points where fatigue failure started. The specimens were left intact, except for the short fatigue cracks that had developed up to the time the testing was discontinued. An examination of the fractures of other beams of the program, as well as those that failed in the compression flanges, might contribute some very interesting fundamental data.

In view of the rather drastic decrease in the unit fatigue strength of the flange of a rolled beam, which reults from the introduction of rivet holes or from the provision of partial length welded cover plates, there would be some cases in which the fatigue resistance of a rolled beam would actually be decreased by the provision of cover plates. However, a large majority of the beams used in bridges are not actually subjected to a large enough number of repetitions of a sufficiently large stress and range of stress to class them as members subjected to fatigue loading.

In static load tests of control specimens similar to some of those tested in fatigue, failure always occurred by buckling of the compression flange at stresses considerably higher than the yield point value, showing that the cover plates were fully effective. In fact, the beams with continuously welded, full-length cover plates developed a calculated static-load bending stress of 59,300 psi., as compared with 43,800 psi. for the plain rolled beams.

Although the results of the fatigue tests that have been conducted seem to warrant some of the general conclusions that have been mentioned, it is evident that other suppositions that have been made must be considered tentative until further evidence is developed.

It is certain that, in general, abrupt changes in stress involving steep stress gradients are undesirable. Sometimes the removal of material at propitious locations is a better solution than increasing the section at points of higher stress.

In fundamental fatigue investigations quite a bit of progress has been made in developing shape factors or notch factors that can be used to predict how much fatigue resistance will be lowered by various kinds and shapes of notches. Although this work helps to orient the judgment of a designer, studies of this kind should be carried further into the field of practical details of design for structures, so that anyone studying them can develop an intuition to anticipate the general kind of stress distribution, severity of notch-effects and stress-concentrations and their aptitude for becoming ironed out in any case with which he becomes confronted.

One of the most interesting developments of immediate practical value to the railway industry, which has emanated largely from the fatigue-testing programs of the Welding Research Council, is the shortening of eye-bar members of truss bridge members, to take the slack out of them, by means of flame "shrinking," a process that has been used quite widely for other purposes such as correcting distortion and straightening bent members. It consists of localized heating by means of an oxyacetylene torch, while the metal is subjected to a restraining influence, provided sometimes by an external jacking force and sometimes by the stiffness of the part, itself, which produces a localized upsetting and shortening.

Bridge engineers wanted to make sure that the fatigue strength of the material would not be reduced by the effect of such heating, which is to a temperature of 1600 to 1800° F., in the procedure as described in a Preliminary Report of Committee 15, Iron and Steel Structures of A.R.E.A., Bulletin 460. This bulletin also contains a complete report of the tests that were made, from which the conclusion was

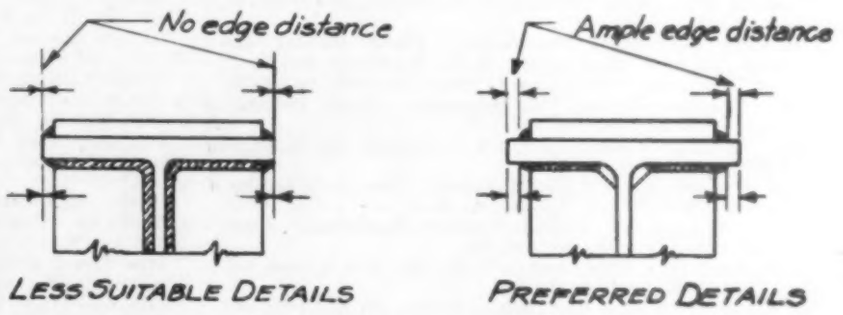


Fig. 16—The Provision of Sufficient Edge Distance, as Indicated, Is Especially Desirable for Welded Members Subjected to Fatigue Loading. Otherwise Edges of Members May Be Scarred or Scalloped at Toes of Welds. Also, It Is Preferable to Avoid Concentrations of Stress-Transfer Near Outer Edges of Flanges Where Fatigue Cracks Are More Likely to Start

drawn that the flame shortening of eyebars does not have any apparent effect upon the fatigue strength of the bars.

Conclusion

Where apparent influences of geometric details and arrangement upon fatigue resistance have been mentioned in this paper, there are no doubt some cases for which the number of specimens has been too few to warrant firm conclusions.

Many of the concepts of design that have been discussed in this paper have become sufficiently well established by the evidence of experience or research to merit their application to at least a limited extent, if no further than to provide a general orientation of design judgment; and some of the concepts have advanced to the point that their significance has been determined quantitatively and they may be applied with little restriction, if any. However, some of them need further confirmation or more definite quantitative evaluation and the establishment of limitations within which they may be applied in a practical manner to design problems.

The tests of frames with restrained connections and stanchions bent in single curvature, which support the methods of calculation used to establish the large true factors of safety that have been cited, apparently have all been conducted upon comparatively small models. In full-size, deeper members, it is possible that the plastic deformations required to satisfy the assumptions of the design theory might be so large in the extreme fibers that they could not be realized under some circumstances of very severe constraint (Fig. 6). Also, near the other extreme, the proportions of some members might be such that they would fail by buckling and instability before the assumed plastic deformations could be realized.

The Welding Research Council of the Engineering Foundation is initiating and extending programs of investigation to the limit of the very considerable financial support that has been made available, as rapidly as adequately staffed and equipped research centers can be set up in engineering schools and other research institutions.

The programs of research at the National Bureau of Standards and at Columbia University, which have been described in this paper, have not yet advanced to the stage where complete reports can be published. The Welding Research Council has published a number of reports covering the fatigue testing (structural) programs at the University of Illinois.

The work at the Bureau of Standards is under the general direction of H. L. Whittemore, Chief of Mechanics Section, and under the direct supervision of Dr. A. H. Stang. The impact tests at Columbia University are being carried out by Professor W. J. Krefeld, Director of Engineering Materials Laboratory, assisted by Dr. E. C. Ingalls and other research assistants. The fatigue testing (structural) programs at the University of Illinois are under the direction of Prof. W. M. Wilson.

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(*Continued on page 1122*)

Control of Welding Stresses by Welding Sequence*

By Paul Ffield†

THE failures experienced by some of the welded ships built during the recent war years stimulated fundamental research into the behavior of welded structures. Welded structures may differ from their riveted counterparts in many ways, one of which is the legacy of welding stresses which is inherent in the fusion welding process. It was only natural then that much of this welded ship research centered around the study of welding stresses.

In its studies of ship failures the Research Department of Bethlehem Steel's Shipbuilding Division included a number of welding stress projects, two of which are discussed in this paper. First was an effort to determine the characteristic pattern of stresses in welded ships. The second investigated the possibilities of making these stresses contribute to the strength of the structure rather than to detract from it.

In discussing these investigations it has been necessary to use some shipbuilding terminology. Certain terms as used here which may not be familiar to those outside the industry are explained below:

Strake—a continuous line or row of plating on a ship's side or deck.

Sheer strake—the top strake of plating on the ship's side.

Deck stringer plate—the outer strake of plating on a deck.

Gunwale—point where outermost edge of main deck meets sheer strake.

Pin bracket—a bracket connecting two longitudinal members through a bulkhead to give the members continuity. See Fig. 18.

Platform—a partial deck.

Bilge—the curved portion of the hull which connects bottom and side plating.

Butts—welded joints oriented athwartship when located in the decks and bottom—vertically when located in the sides.

Seams—welded joints in the decks, sides and bottom which are oriented in a fore-and-aft direction.

Longitudinal weld stress—stress acting in a direction parallel to the axis of a weld.

Traverse weld stress—stress acting in a direction normal to axis of a weld.

Fore-and-aft stress—stress acting lengthwise with respect to the ship. In a deck butt, for example, a transverse weld stress is also a fore-and-aft stress.

Athwartship stress—stress acting across the width of the ship. In a deck butt the longitudinal weld stress is also an athwartship stress.

Sagging—tendency of the ship to arch downward or sag when the ship is in the trough of a wave.

Hogging—opposite of sagging; tendency of the ship to arch upward when poised on the peak of a wave.

Residual Stress Pattern in Welded Ships

Studies reported by the National Defense Research Council,[1-8] together with our own work on Bethlehem-Fairfield Liberty ships, show that there is a characteristic residual welding stress pattern in the main deck of the ships investigated (Fig. 1). The stress patterns shown resulted principally from the automatic welding of deck seams. A high longitudinal tensile stress is developed in the weld acting in a fore-and-aft direction. This stress falls off rapidly in the plate, reaching zero about 4 in. from the weld. From this point a moderate compressive stress exists in the main body of the plate. Athwartship deck stresses (i.e., traverse weld stresses), are fairly constant and are

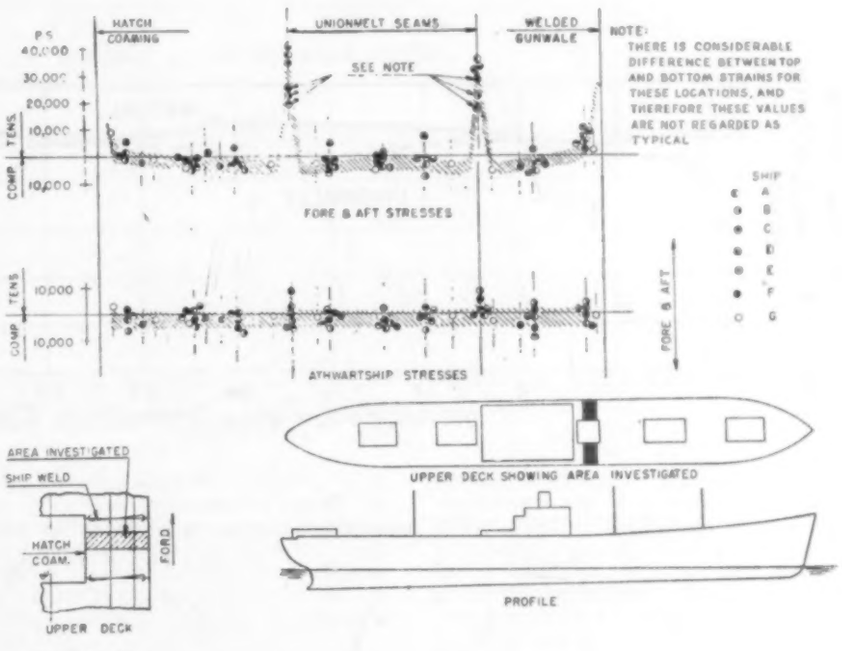

Fig. 1—Upper Deck Welding Stress Patterns in 7 Beth-Fairfield Liberty Ships

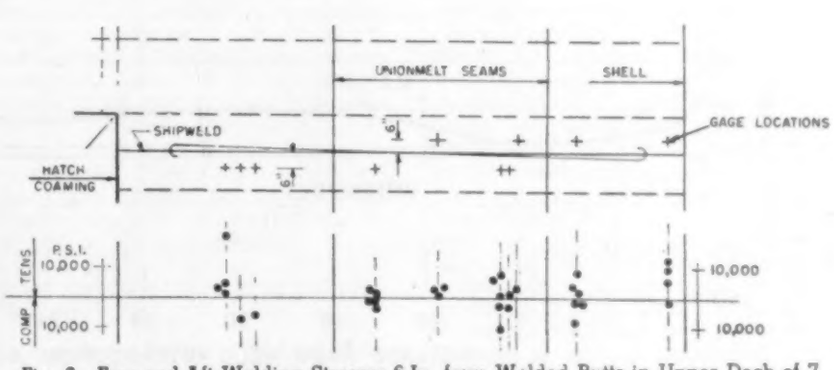

Fig. 2—Fore-and-Aft Welding Stresses 6 In. from Welded Butts in Upper Deck of 7 Beth-Fairfield Liberty Ships

* Scheduled for Twenty-Seventh Annual Meeting, A.W.S., Atlantic City, N. J., week of Nov. 17, 1946.

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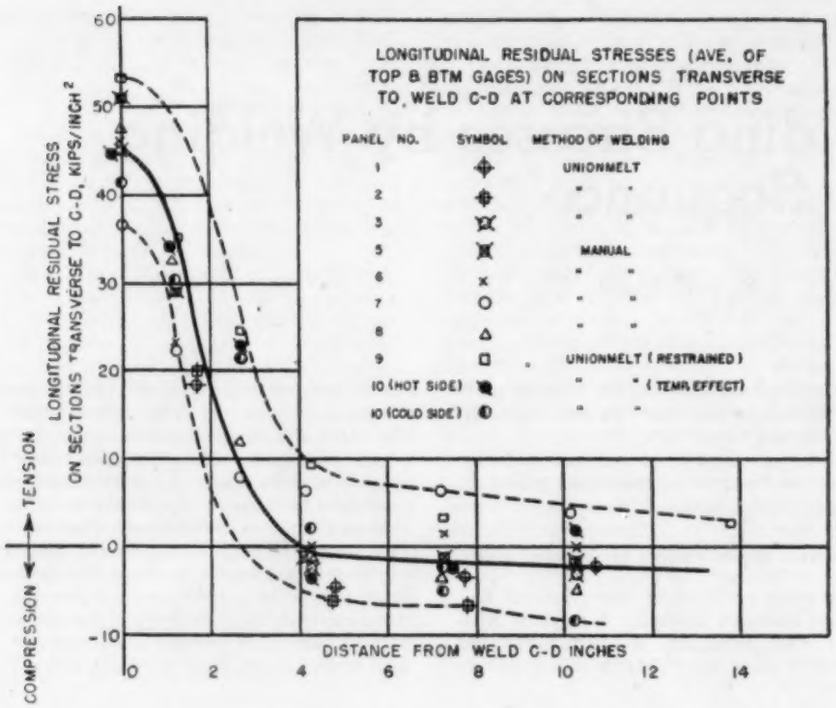
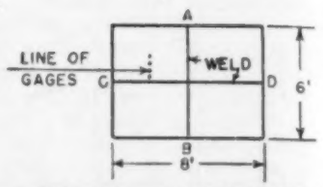
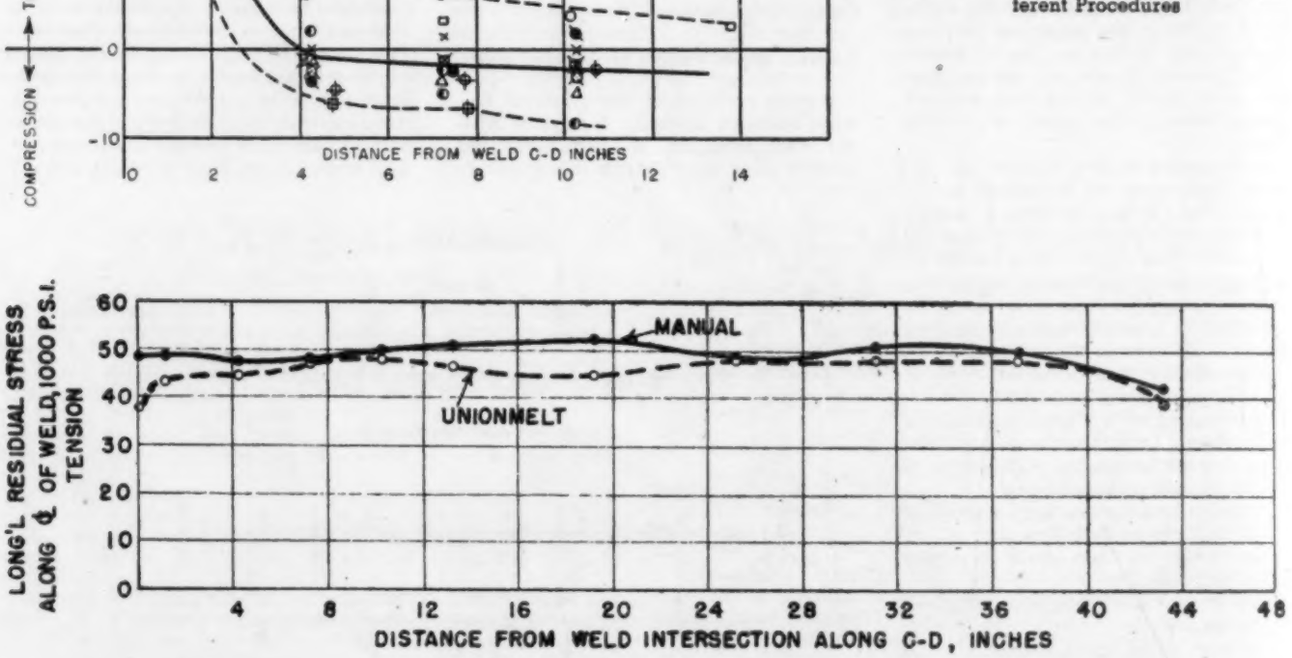




Source-NDRC Report M-190 (OSRD No. 3176) Dated Jan. 14, 1944 Fig. 11 Pg. 28

Fig. 3—Summary Plot of Longitudinal Stress in 1-In. Plate Welded with 10 Different Procedures



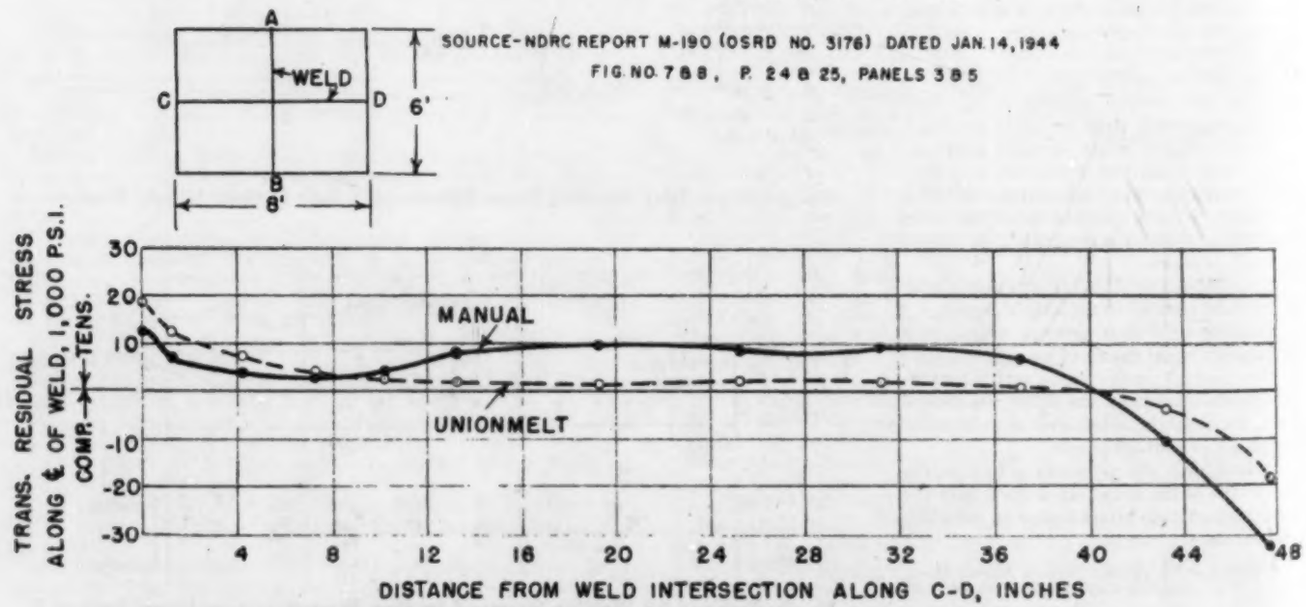


Fig. 4—Typical Longitudinal and Transverse Welding Stresses in 1-In. Plates

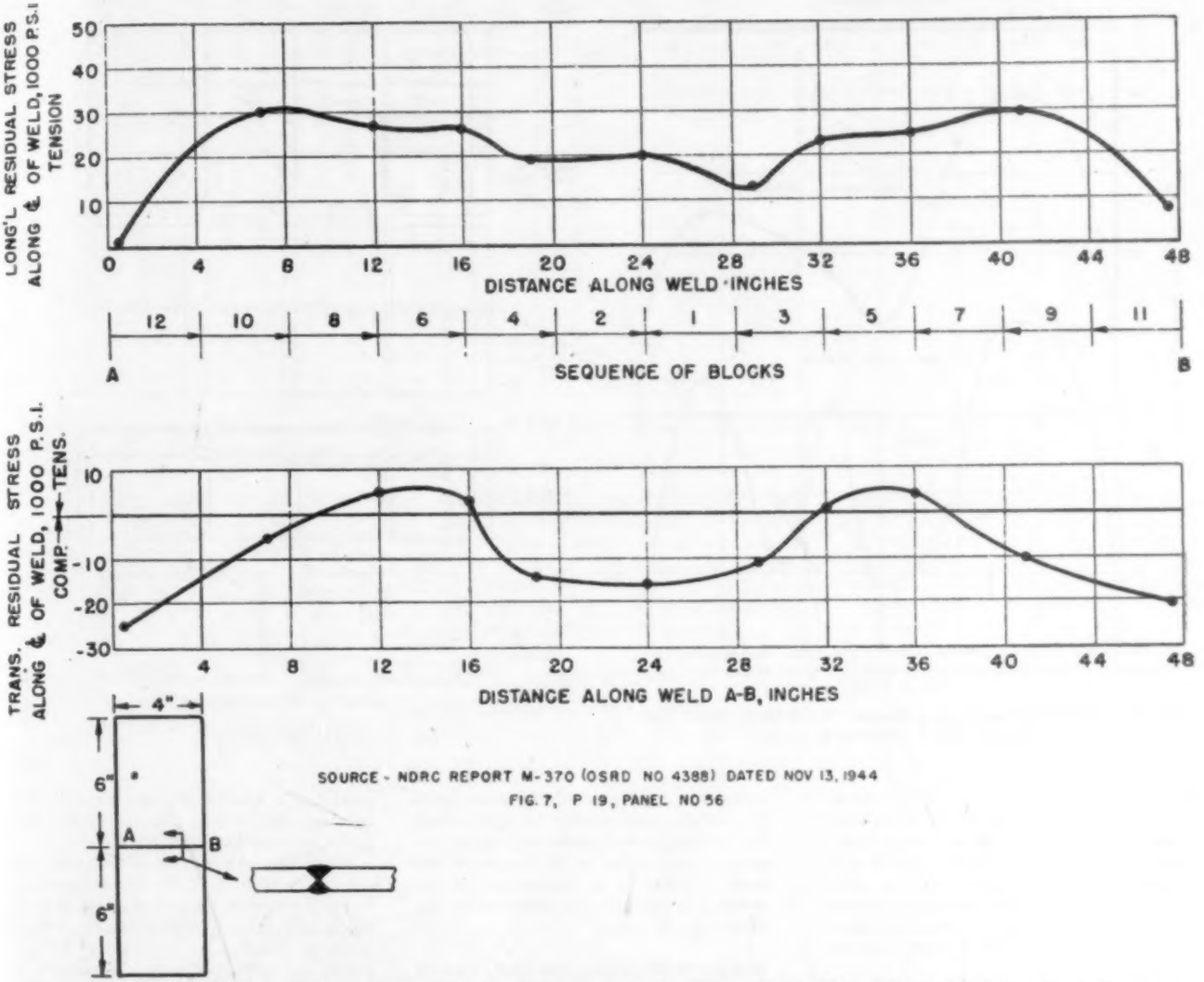


Fig. 5—Longitudinal and Transverse Residual Stress in 1-In. Plate Back Step Block Welded from Center Toward Edges and Cooled Below 125° F. Between Each Block

moderate compression, showing only a slight tendency toward tension in the immediate vicinity of the weld.

Figure 2 shows the stresses in the deck of the same vessels but in the vicinity of the manually welded butts. The transverse weld stresses (which act in a fore-and-aft direction) show some variation along these welds. Unlike the transverse stresses in the Unionmelt weld, those in the manual weld do not show any pronounced tendency toward compression, actually more gages registered tension than compresssion. Furthermore the transverse stresses, either tension or compression, trend toward higher values when compared to their counterparts in the Unionmelt seam (transverse stresses, lower part of Fig. 1). In contrast to the Unionmelt weld which is deposited as a continuous operation, the weld metal in these butts is deposited in short increments, each representing the consumption of one electrode. Intermittent cooling therefore takes place when the operator changes electrodes. In addition, the deposition of single electrodes permits many variations in the exact sequence followed in building up a weld and in progression along the joint. It is probable that these variables all contribute to the irregular stress distribution around the manually welded butts shown in Fig. 2. Not plotted in the figure are the longitudinal weld stresses (athwartship stresses) which are in the order of 40,000 psi. and fairly constant throughout the length of the weld.

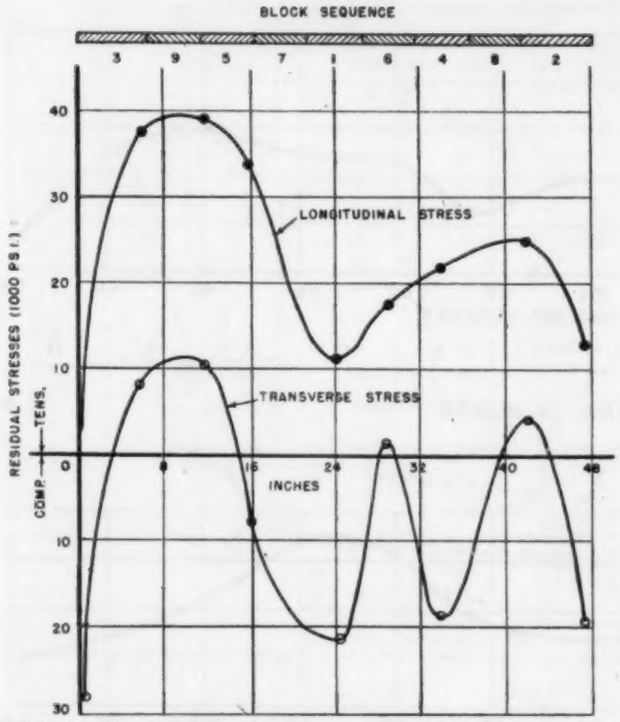
In summary, the stress pattern in Bethlehem-Fairfield Liberty ships shows that in the machine-welded seams the longitudinal and transverse stresses are established within fairly close limits. In the longitudinal direction, high tension is generated in the weld and moderate compression in the plate. In the transverse direction moderate compression is developed in both weld and plate. The manually welded butts show a somewhat higher order of magnitude for the transverse stresses which are variable and do not form a characteristic pattern. In all probability this is due to the variations in sequence which are likely in manual welding as noted above.

Residual Stress Pattern in Welded Plates

Using comparatively small plates, the N.D.R.C. made exhaustive studies to determine the effects of welding procedure on stress magnitude. Their work showed that stress patterns similar to those in the decks of Liberty ships are present in welded plates. Figure 3 is a summary plot of longitudinal stresses in 1-in. plates welded with ten different procedures. The similarity of residual stress for all ten procedures is noteworthy.

One phase of this N.D.R.C. work was directed toward the possibility of reducing the high longitudinal weld stress. Figure 4 is a typical N.D.R.C. plot of welding stresses for a machine (Unionmelt) and a manual weld in a 1-in. plate. The machine weld was a 60° double V made in three passes. The manual weld was also a 60° double V but made in six passes. The machine welding was a continuous operation from end to end of the plate for each pass, whereas the passes for the manual weld were of necessity a series of short beads each representing the deposition of an electrode. The constancy of the residual stresses in these welds is noteworthy.

This N.D.R.C. work showed that some reduction in the high longitudinal stress was effected with special manual welding procedures. For example, a progressive


BLOCK SEQUENCE
3 9 5 7 1 6 4 8 2
RESIDUAL STRESSES (1000 PS I.)
COMP. — TENS.
LONGITUDINAL STRESS
TRANSVERSE STRESS
INCHES
0 8 16 24 32 40 48
40 30 20 10 0 10 20 30

SOURCE—NDRC REPORT M-370 (OSRD NO. 4388) Dated Nov. 13, 1944
FIG. 9, P. 24

Fig. 6—Residual Stresses in a Manual Weld Made by a Wandering Block Procedure

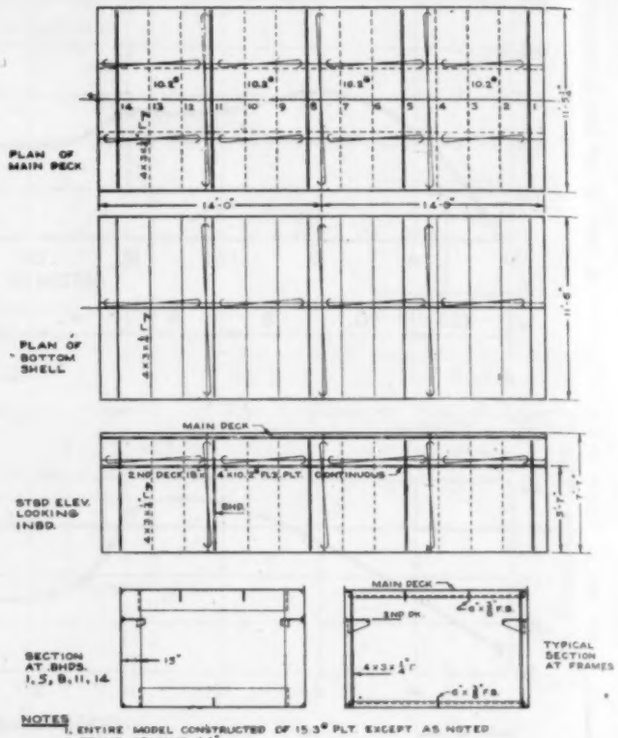

PLAN OF MAIN DECK
PLAN OF BOTTOM SHELL
MAIN DECK
STBD ELEV. LOOKING INBD.
SECTION AT BHDS. 1, 5, 8, 11, 14
TYPICAL SECTION AT FRAMES
NOTES
1. ENTIRE MODEL CONSTRUCTED OF 15.3# PLT EXCEPT AS NOTED
2. FRAME SPACING 24"

Fig. 7—Girth Weld Model

block* system using 4-in. blocks back stepped from the center to the edges with cooling below 125° F. between each block brought this stress down to 30,000 psi. maximum (upper section of Fig. 5). Also noteworthy is the variation in transverse stress, with the presence of alternate zones of tension and compression (lower section of Fig. 5).

Even more pronounced is the variation of transverse stress shown in the lower section of Fig. 6 which represents a wandering block system. Attention is directed to the fact that blocks 1, 2 and 3, which were deposited first, have the highest transverse compression, whereas the last blocks (8 and 9) contain the highest transverse tension. It is possible that an additional gage at the 20-in. station would have shown a tension hump for block 7 (similar to block 6) and a gage at 38 in. would show a higher tension peak for block 8.

For the purposes of this paper, the significant inferences to be drawn from the above N.D.R.C. studies on small plates are:

1. The longitudinal stress in a manual weld may be reduced by controlling the welding procedure but the sign of the stress will always be tension.
2. The magnitude of the transverse stresses in manual welds is unlikely to be reduced appreciably by controlling the welding procedure but the sign of the stress at any point in the length of the weld is likely to be dependent on the welding procedure especially when the block system is used.

Shipyards employing the block system in their production welding discovered the inference 2 above empirically. In the welding of critical joints, experience showed them which blocks were likely to crack and which were not. They also suspected that a wandering or selective block sequence produced a medley of transverse stresses because they found this procedure less likely to cause distortion troubles.

From the foregoing it is apparent that one characteristic of the block system of welding is to create reaction stresses. Each block as it is completed may act as a fulcrum or focal point of rigidity, to telegraph the stresses due to shrinking from one part of a welded seam to another. This is particularly true in the case of a selective block sequence and as shown in Fig. 6 it is possible to forecast the zones of stress when the order of deposition of the blocks is known.

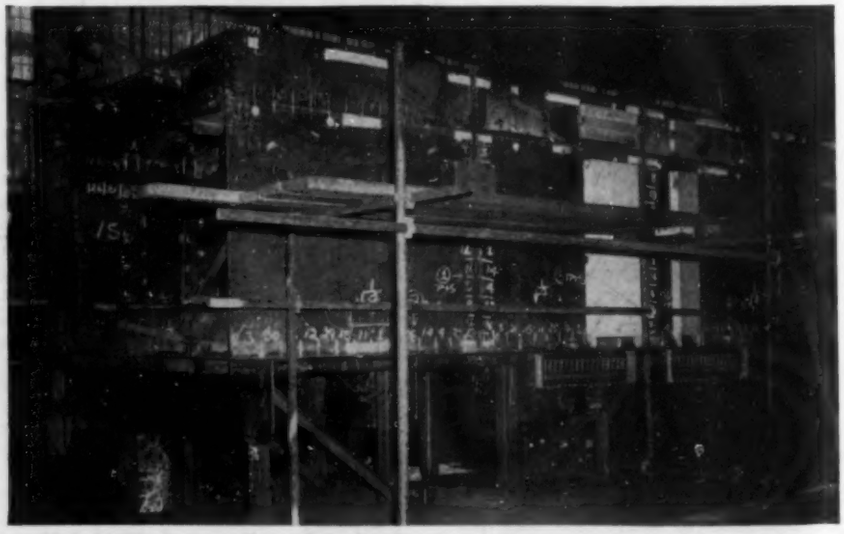


Fig. 8—Photograph of Model Nearing Completion. Plywood Covers Are Installed to Protect Gages Each Side of Girth Butt. Gages Are Wired to Central Stations on Each Side of the Model. Note Marking for Sequence of Welding

* *Block welding*—The deposition of welding in comparatively short increments, the weld metal being deposited to the full thickness of the plate. In heavy plates blocks are sometimes built up to half thickness.

Progressive block welding—Block welding where the blocks proceed along the weld in a progressive sequence (Fig. 5) either from one end to the other or from the center to the outside.

Wandering block welding—Block welding where "starting" blocks may be made at several points in a joint (Fig. 6).

Selective block welding—Similar to wandering block but where the sequence of completing the blocks and the joints in a structure is selected to create a predetermined stress pattern.

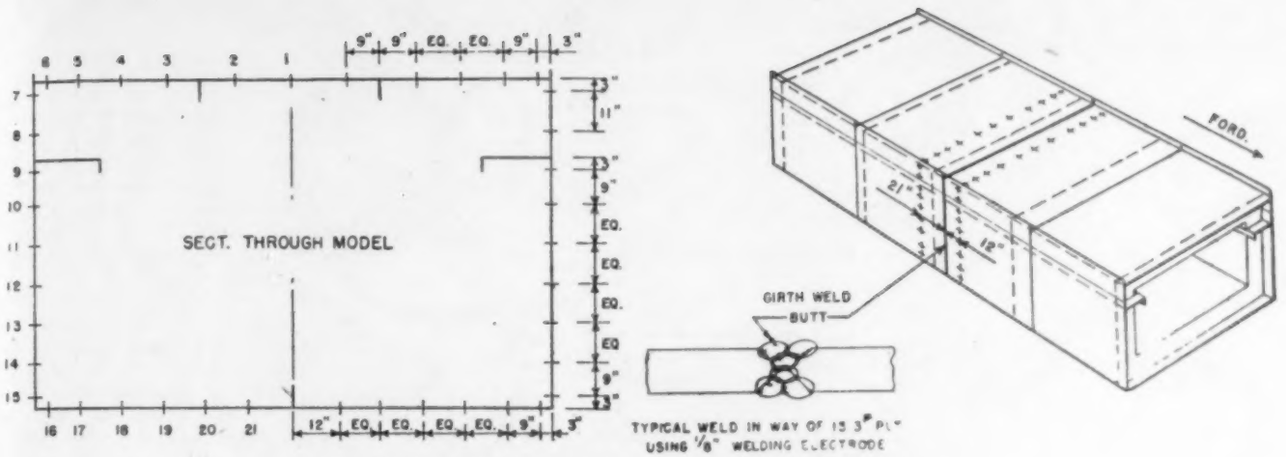


Fig. 9—Gage Locations for Girth Weld Model

Welding Stress Studies in the Bethlehem Ship Research Program

An examination of welded ship failures showed that those cracks which originated in welds rather than in design notches, invariably started in butts rather than seams. Since the cracks these ships experienced were characteristically oriented athwartship, they must have been caused by stresses acting in a fore-and-aft direction. It therefore follows that if residual welding stresses contributed to these failures, it was the transverse stresses (fore-and-aft direction) in the butt welds which were significant. With this in mind it was decided to direct one phase of our ship research to the control of residual welding stresses. Influencing this decision was the fact that local stress-relieving methods under development at that time were not particularly effective in reducing the transverse stresses in butt welds of appreciable length. In other words, it might be possible to stress relieve locally the fore-and-aft stresses in seams but the fore-and-aft stresses in the more critical butts were unlikely to respond to local heat treatment.

It was appreciated that it probably would not be possible to reduce the magnitude of the transverse stresses but if the sign of these stresses could be controlled at will, i.e., if the welding procedure could influence the zones of compression or tension in the structure, the object of this particular project in our welded ship research program would have been accomplished. The premise guiding this phase of the work was that if uncontrolled welding stresses could on occasion precipitate failure by weakening the structure, then if it were possible to exercise positive control over these stresses, they might be made to contribute to the strength of the structure rather than detract from it.

The value of such a development is seen when it is considered that a ship in a seaway is subjected to hogging and sagging forces. Under these conditions the neutral axis is located about halfway between the upper deck and bottom while the deck and bottom are subject to tension or compression. It is conceivable that if the deck is in tension due to residual stresses, further tension resulting from hogging might precipitate a failure under the right conditions. But if the residual tension stresses could be driven toward the neutral axis in the side shell and residual compression stresses concentrated in the deck and bottom, the tension stresses in the deck and bottom induced by hogging and sagging at sea would, in effect, be reduced by the amount of residual compression.

Model Experiments

The basic procedure in this investigation to study the possibility of controlling the transverse weld stresses in girth butts, was to place electric resistance strain gages in a band at each side of a girth butt prior to welding and to measure the direct stress resulting from the welding operation, correlating these stresses with the welding procedure.

For these studies a large model was constructed geometrically similar to the midship section of a Liberty ship (Figs. 7 and 8). It measured 28 ft. long, $11\frac{1}{2}$ ft. wide and $7\frac{1}{2}$ ft. deep—one-fifth the size of

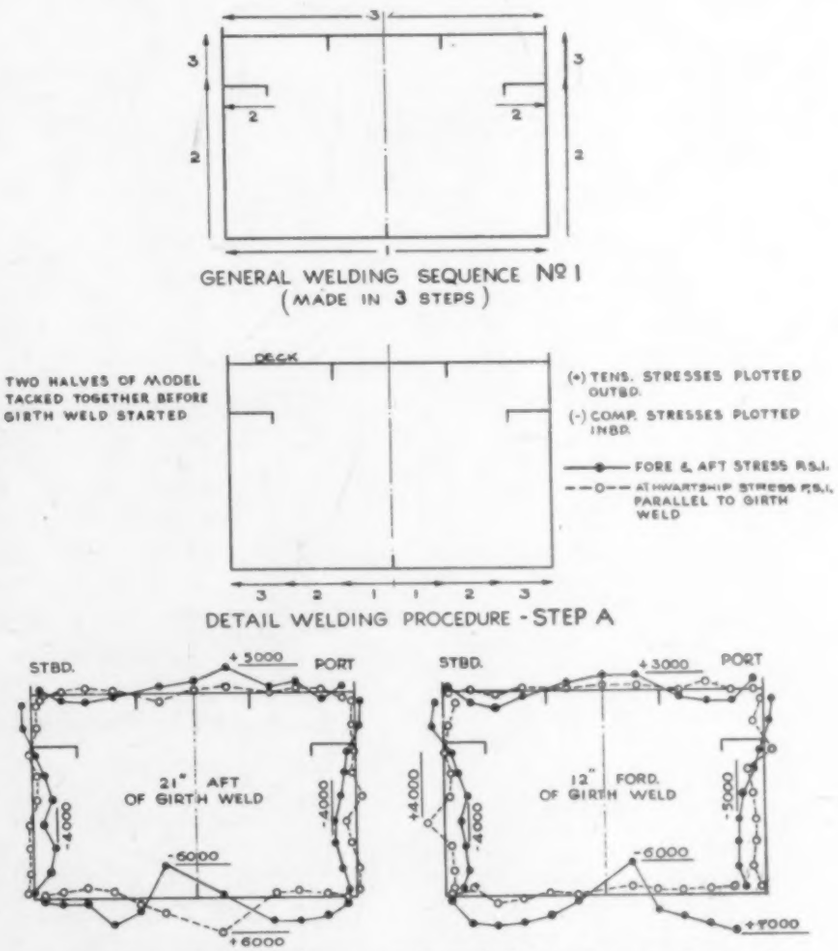


Fig. 10—Stresses Due to Welding on Girth Weld Model, Sequence 1, Step A

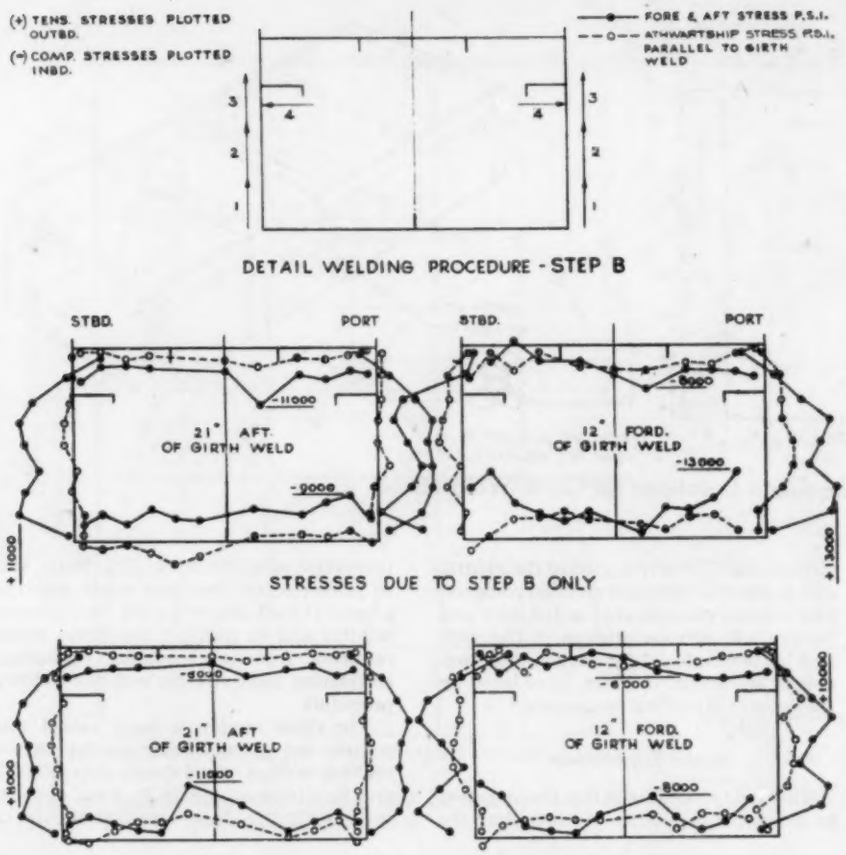

(+) TENS. STRESSES PLOTTED OUTBD.
(-) COMP. STRESSES PLOTTED INBD.
FORE & AFT STRESS P.S.I.
ATHWARTSHIP STRESS P.S.I. PARALLEL TO GIRTH WELD
DETAIL WELDING PROCEDURE - STEP B
STBD.
PORT
21" AFT OF GIRTH WELD
12" FORD. OF GIRTH WELD
STRESSES DUE TO STEP B ONLY
SUMMATION OF STRESSES DUE TO STEPS A & B

Fig. 11—Stresses Due to Welding on Girth Weld Model, Sequence 1, Step B

after each test, hence it was abandoned in favor of the mercury connector[5] which permitted direct connection of the strain recorder to the gage. Using two strain indicators, six men could read all the 164 rosettes (492 elements) in about $1^1/_2$ hr. Readings were made with the operators on the staging to avoid errors due to local bending of the plate panels.

All work on the model was carried out in a closed shop to avoid stress variation due to atmospheric temperature differentials. A test made during a lunch period when the building doors were opened indicated that a 15° F. drop in ambient temperature created insignificant stress changes.

The procedure for strain gage readings was to make a series of "zero" readings prior to welding, following the techniques described in reference 4 to insure stability of gage readings. Gages were then read after welding was completed and the weldment had cooled to ambient temperature. Subsequent check readings were taken at intervals to insure that the gages were stable. In the study of some sequences, readings were taken at the completion of each step in the welding so that its significance could be determined.

In long-term tests of this kind, the reliability of some electric strain gages may be questionable. In such cases, check comparisons can be made between port and starboard gages or between forward and after gages at corresponding locations 12

the equivalent ship section. Plate was $^3/_8$ in. (15.3 lb.)—one-half the thickness of Liberty ship plating. For the first tests the bilges were left square in order to delineate the stress pattern more positively. The actual welding was scaled down somewhat but still was typical of ship welding. A double-V butt was used, the weld being made in six passes of $^1/_8$-in. electrodes. The model was constructed in two sections, stress relieved, then joined by a girth weld. This gave the effect of welding two stress-free "subassemblies."

A band of electric strain gages of the three-element rosette type was located 12-in. forward of the girth butt. A second band was placed 21 in. aft of the weld (Fig. 9). All gages were duplicated on the opposite surface of the plate to cancel any effect of bending. This coverage required a minimum of 164 rosettes.

Tests showed that under the conditions of welding on the model, gages no nearer than 9 in. from the butt were unlikely to be affected by welding heat.

It was possible to use the model repeatedly—after the study of a girth weld had been completed the weld was cut out and the two halves of the model stress relieved. They were then ready for the next test.

Reference 4 fully describes the strain gage technique. The first gage installation involved a central wiring system (Fig. 8). This proved time consuming to install and would require removal for stress relieving

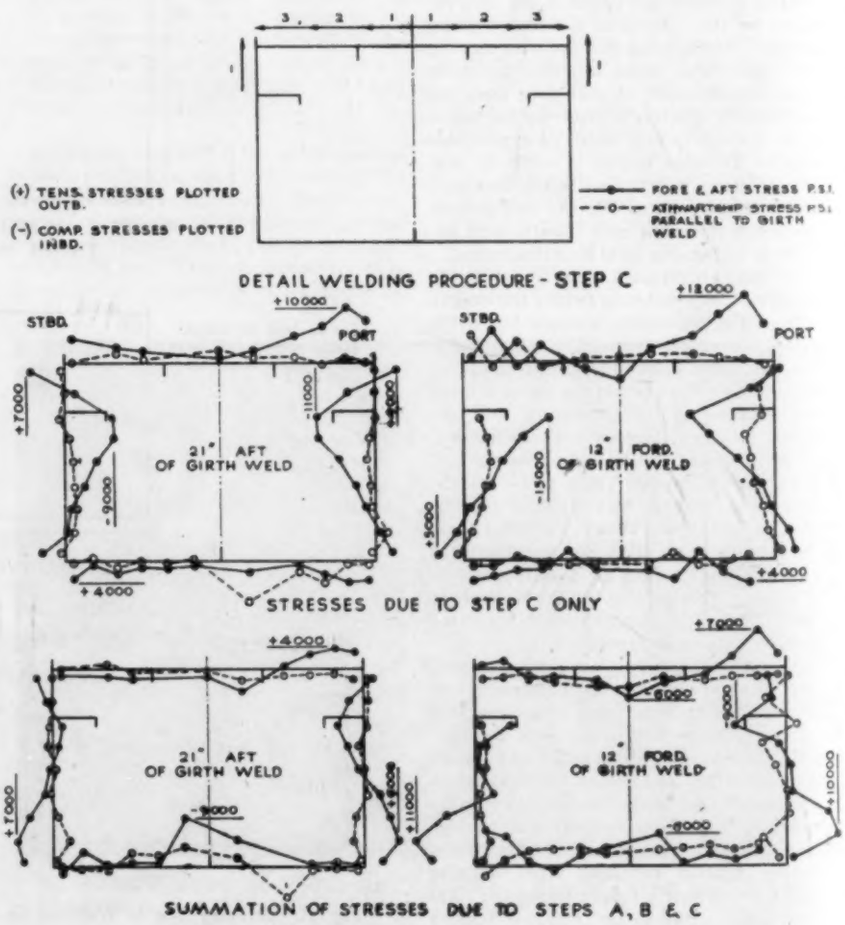

(+) TENS. STRESSES PLOTTED OUTB.
(-) COMP. STRESSES PLOTTED INBD.
FORE & AFT STRESS P.S.I.
ATHWARTSHIP STRESS P.S.I. PARALLEL TO GIRTH WELD
DETAIL WELDING PROCEDURE - STEP C
STBD.
PORT
21" AFT OF GIRTH WELD
12" FORD. OF GIRTH WELD
STRESSES DUE TO STEP C ONLY
SUMMATION OF STRESSES DUE TO STEPS A, B & C

Fig. 12—Stresses Due to Welding on Girth Weld Model, Sequence 1, Step C

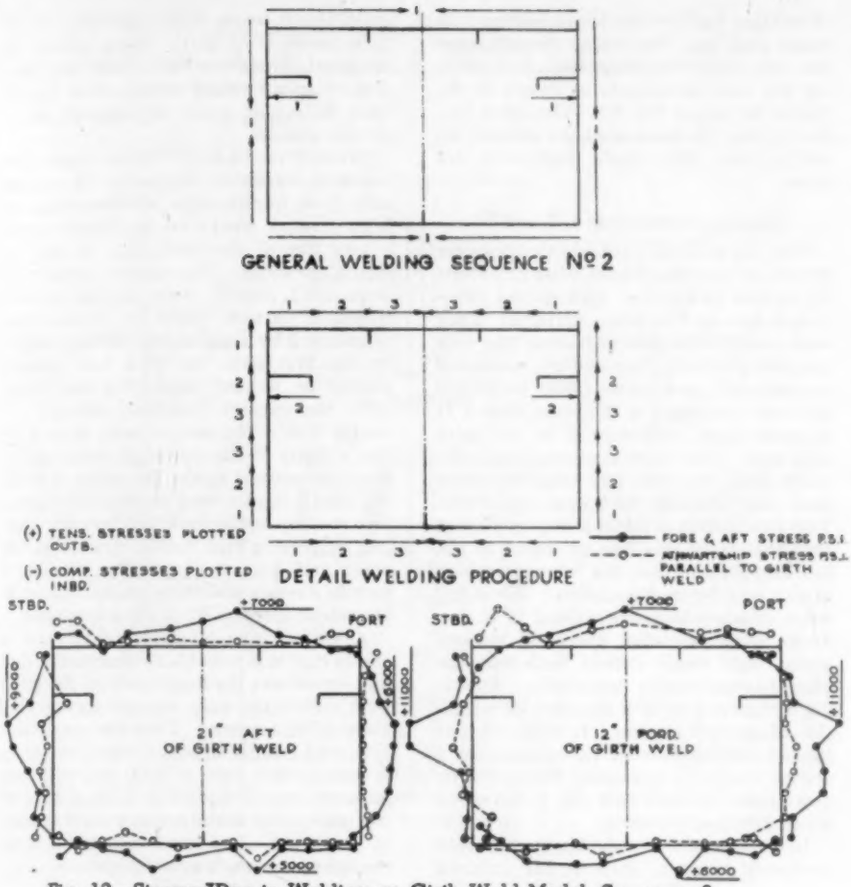


Fig. 13—Stresses Due to Welding on Girth Weld Model, Sequence 2

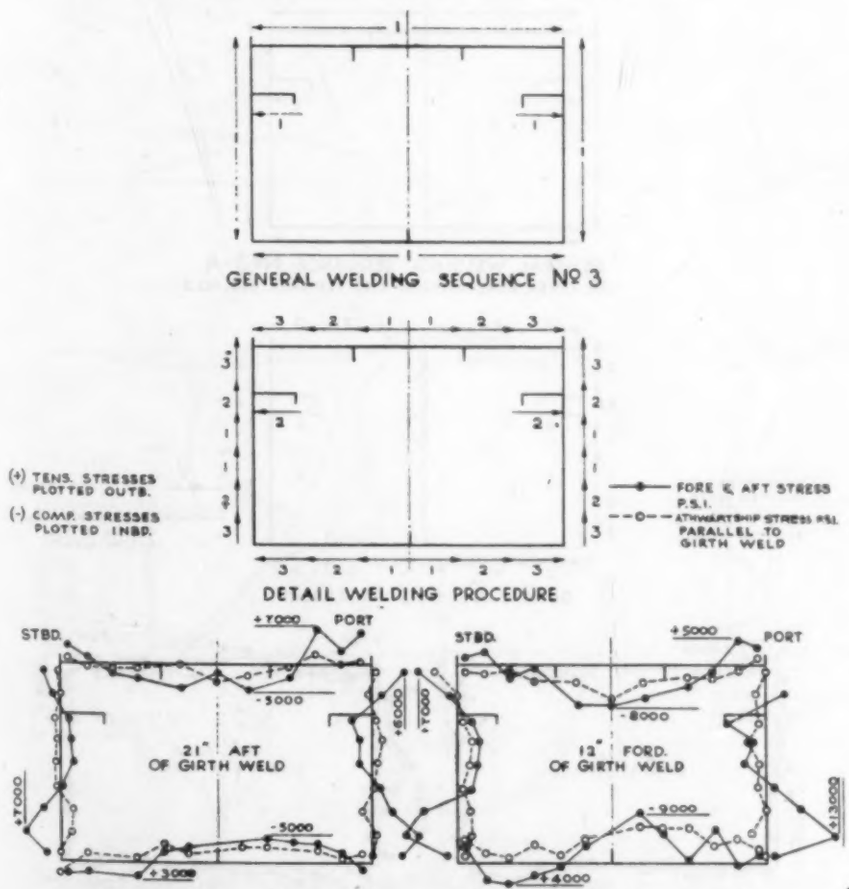


Fig. 14—Stresses Due to Welding on Girth Weld Model, Sequence 3

and 21 in. away from the weld. The latter should be in reasonable agreement, with the gages in the 12-in. band giving slightly higher values. Results which show similar stress patterns between port and starboard, or in the 12-and 21-in. bands should be completely reliable.

A few comparisons were made of these direct-read strain readings by trepanning some of the gages. Correlation was good at these particular locations as shown in Appendix 1. In 9 out of 10 plugs trepanned, the values were within 3000 psi. of the direct-read gages. Part of this difference could be due to rolling stresses in the plate which may not have been eliminated entirely by the stress-relieving treatment. Appendix 2 shows that these rolling stresses may be appreciable.

Model Welding Sequences 1, 2, 3 and 3A

Figures 10 through 15 show the results obtained in these sequences. All welds were of the double-V type and completed in six passes. The progressive block system was specified for each sequence, using long blocks 18–24 in. in length—each block being completed to full thickness of six passes before progressing to the next adjacent block. Port and starboard were welded simultaneously and a maximum of four welders was used.

Only the stresses normal to the girth weld are discussed here since only they have a direct bearing on the main thesis.

Sequence 1 (Figs. 10–12)

Sequence 1, as shown in the upper portion of Fig. 10, was made in 3 steps and is typical of that most generally used in all shipyards, i.e., welding from the center line outboard and from the bottom up.

Step A comprised the welding of the bottom, starting at the center and working outboard, as indicated in the center portion of Fig. 10. In the lower portion of Fig. 10 the stress values resulting from this step are plotted. The amount of restraint offered by the tack welds appears considerable as evidenced by the magnitude of the stresses (3000 to 5000 psi.) at those portions of the model which were only tack welded. Step A also suggests that the shrinkage of blocks 2, port and starboard, caused the weld metal at block 1 to be compressed.

Step B consisted of welding the sides and second deck in 4 blocks, progressing up the side to the lower edge of the sheer strake as indicated in the upper section of Fig. 11. It will be noted that the fore-and-aft stresses built up to appreciable magnitudes. The stresses due to this welding only are plotted in the center section of Fig. 11 and consist of high tension in the sides, with fairly high compression in the deck and bottom. The stresses created by step B have cancelled out the tension in the bottom created by step A and the sum of the stresses resulting from steps A and B has placed the entire deck and bottom in compression and the sides in tension (Fig. 11, lower section). This indicates rather clearly that a weld made second in a sequence of two steps should contain primarily tension stresses. Conversely, the weld made in the first step would be likely to contain principally com-

pression stresses or tensile stresses of a low order. Again the restraining effect of the remaining tack welds in the deck should be noted.

Step C completed the welding of the girth butt. Welding was started simultaneously at the center line and at the bottom of the sheer strake (Fig. 12, upper portion). This step created appreciable bending in the model. Reference to the center portion of Fig. 12 shows that compressive stresses in the side below this welding were high, reaching 15,000 psi. 12 in. from the weld and 10,000 psi. 21 in. away. The stresses resulting from this last step created a final pattern at the girth consisting essentially of peaks of tension at the corners and peaks of compression at the center line and neutral axis (Fig. 12, lower section).

The results of sequence 1 show that it is quite necessary to consider each individual step in the welding process when dealing with accumulative welding stresses (the stresses of each step must be added to those of the previous step), and thus the hereditary influence of each step is carried through to the final stress pattern. The significance of this is apparent when it is appreciated that stresses of opposite sign cancel out whereas those of similar sign are additive.

Sequence 2 (Fig. 13)

This sequence was planned in an attempt to create a more ideal stress pattern, consisting of compression in the corners and tension at the center line and neutral axis. The sequence of welding is shown in the upper portion of Fig. 13. Essentially, it consists of starting the weld at the corners and proceeding toward the center line and neutral axis, since it was reasoned that the last portion of the structure welded would be pulled into tension while previously welded sections would be subject to compression. It is noted from the figure that although the general welding progress was downward in the upper side shell ends, each individual block was necessarily welded upward so the weld metal could be easily deposited.

It is interesting to observe in the lower section of Fig. 13 that the fundamental purpose of this sequence is accomplished in that no high tensile stresses appear in the corners. For some unexplained reason, the stresses recorded do not balance. The results of sequenc 2 strongly suggested that the pattern of stress could be controlled by the welding sequence. To confirm this, sequence 3 was planned.

Sequence 3 (Fig. 14)

In this sequence it was decided to reverse the stress pattern obtained in sequence 2 by reversing the order of block deposition (Fig. 14, upper portion). Reference to the lower portion of Fig. 14 shows that in this test a better balance of recorded stress was obtained and the results are truly opposite to those obtained in sequence 2, thus confirming that the stress pattern in way of the girth butt can be controlled by welding sequence.

Sequence 3A (Fig. 15)

After completing sequence 3, it was decided to see what effect a final single bead of welding had on this stress pattern. A single pass was then made directly over the completed weld of sequence 3, depositing the weld increments as shown in the center section of Fig. 15. The lower section of Fig. 15 shows that the stresses resulting from this single pass were not great.

Results of Sequences 1, 2 and 3

The aim of these tests was to determine the effects of welding a complete girth butt by various procedures with special reference to fore-and-aft stress patterns. They were successful in demonstrating that with this size geometry, fore-and-aft stresses of considerable magnitude (5000 to 13,000 psi.) are developed in the plate 12 and 21 in. away from, and normal to, the girth butt weld. The stress diminishes with distance from the weld and therefore these tests deal primarily with local conditions. This localization of stress is due to the fact that the model was free to shrink in the fore-and-aft direction, not being restrained in any way by its foundation. When full scale subassemblies are welded in a ship under some restraint, the weld stresses across butt welds extend well into the plate in considerable magnitude. Appendix 3 reports part of a separate investigation of erection stresses. It indicates that fore-and-aft stresses in the vicinity of a closing deck butt averaging 4000 psi. 3 ft. away from the weld had only fallen off to about 3000 psi. 9 ft. away.

In the case of the model the stress would obviously taper to zero at the extreme ends, but it seems likely that the hereditary stresses of girth butts would be apparent throughout the middle body section of an all-welded vessel, their magnitude depending upon the amount of restraint present.

While it might be desirable to place the zones of maximum tension in the neutral axis, it is questionable whether zones of high tension would be beneficial in the center line of the deck, e.g., in way of hatch openings. The stress pattern of sequence 1, step B, suggests that a more desirable pattern might be obtained for sequence 2 by making two distinct steps: in the first step, the deck and bottom should be welded, depositing the blocks from the corners (gunwale) toward the center line. The second step should be the welding of the side shell, working toward the neutral axis. The result of welding step 2 should tend to create compressive stresses in the deck and bottom without generating high tensile stresses in the sheer and bilge strakes. The maximum tensile stresses would be concentrated in the side in the vicinity of the neutral axis.

A comparison of sequences 2 and 3 shows that it is possible to change the sign and sometimes the magnitude of the girth butt transverse weld stresses by varying the welding sequence. These two sequences produced exactly opposite stress patterns. A compression zone of 5000 psi. with one sequence corresponds to a tension zone of the same order in the other, a total change of 10,000 psi. At a few locations the total change was as much as 15,000 psi.

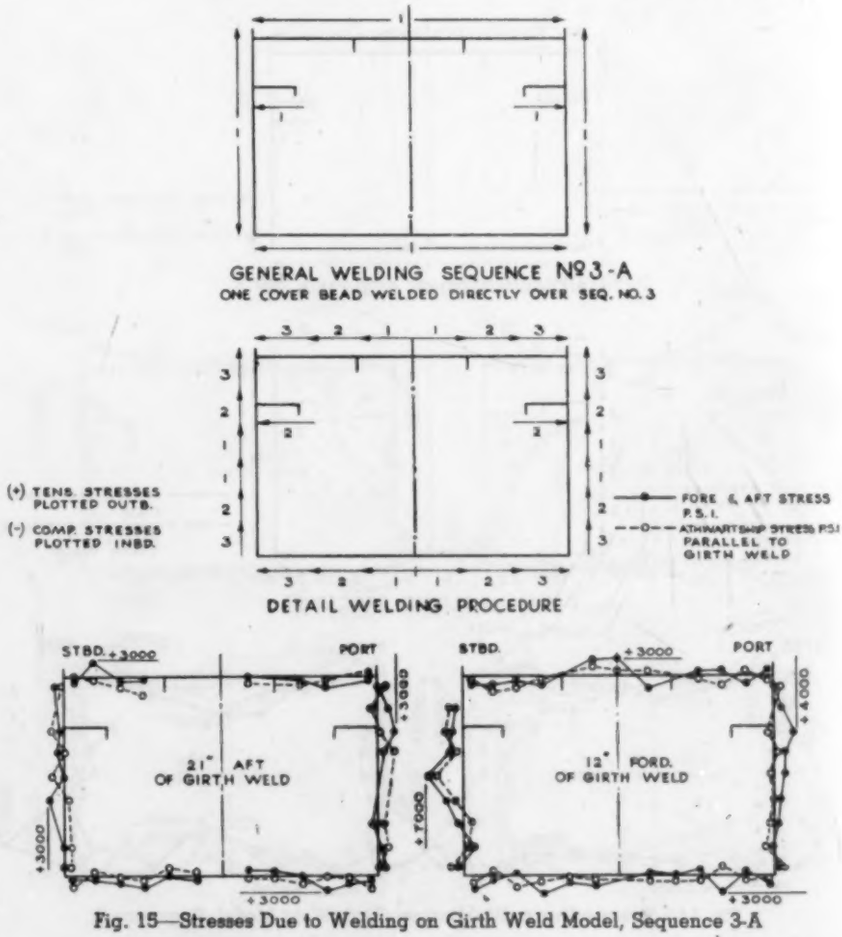


Fig. 15—Stresses Due to Welding on Girth Weld Model, Sequence 3-A

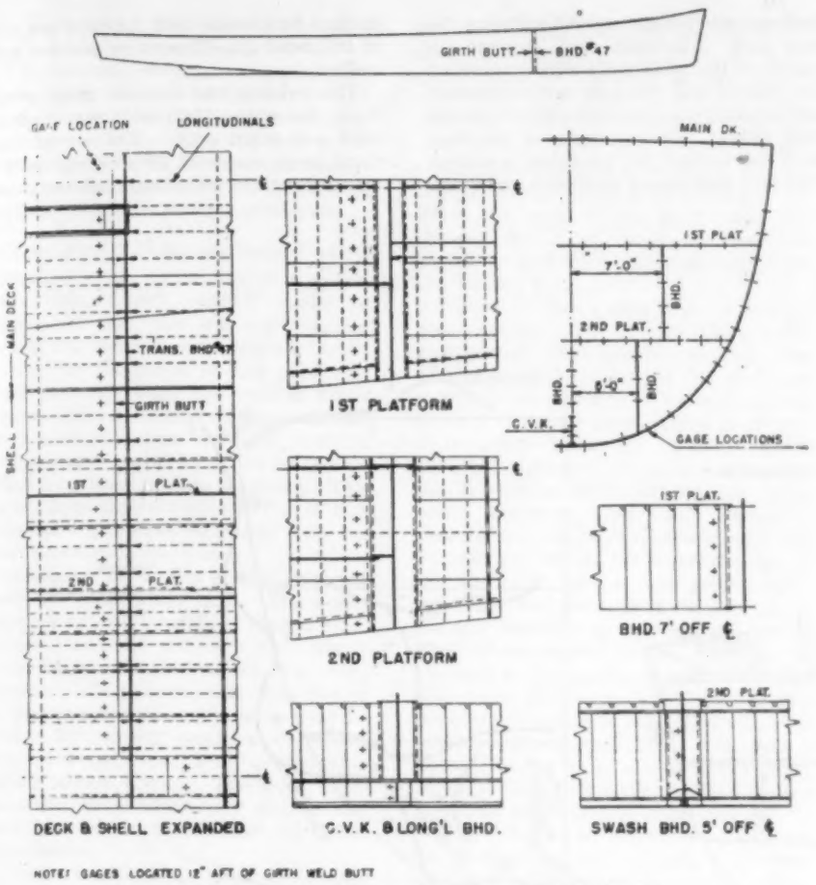


Fig. 16—Gage Locations and Structural Details for DE

Full-Scale Check Test on Destroyer Escort

Before drawing final conclusions from the model, it was deemed advisable to determine if the stress patterns produced in the model were typical of those occurring in a ship. An opportunity presented itself at the Bethlehem-Hingham Yard to make a full-scale investigation of a shell girth weld on a Destroyer Escort under construction at that yard.

The girth selected for this investigation was located 9 in. aft of frame 47 which is the first girth weld forward of the machinery space. Figure 16 shows the location of bulkhead 47 in relation to the ship as a whole and also indicates the stations for the strain gages. Gages were installed on the starboard side of the ship 12 in. aft of the girth butt. They were placed on both sides of the plate at each station and were located on the vertical keel, flat keel, bottom shell, side shell, main deck, first and second platforms and longitudinal bulkheads. Details of the instrumentation with particular reference to waterproofing and protection are given in reference 4.

The welding of the girth and interior structure was carried out simultaneously on the port and starboard sides. Most shell joints were single-V welds. The sequence of welding was in accordance with standard practice and consisted, in general, of welding from the center line outboard.

It was necessary to deviate somewhat from the Bethlehem-Hingham standard method of erection in order to leave the girth weld free for this investigation. However, no unreasonable requests were made

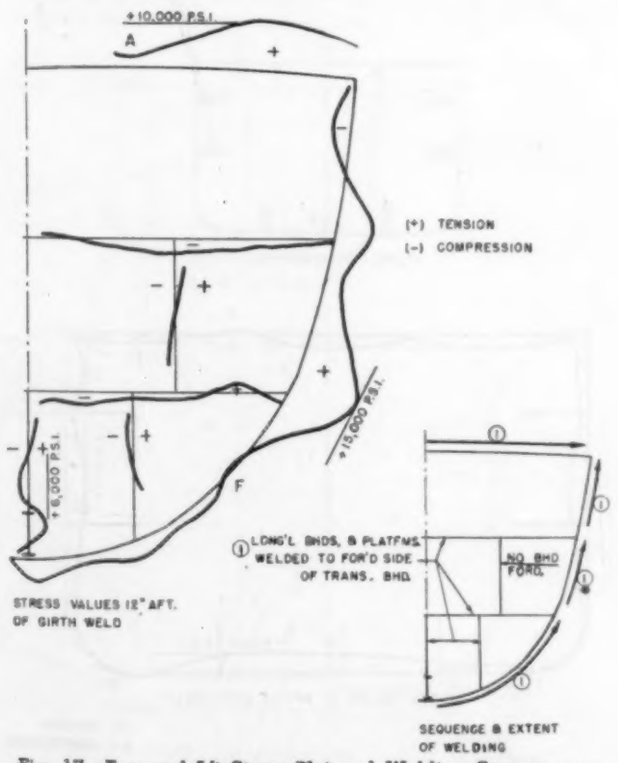


Fig. 17—Fore-and-Aft Stress Plot and Welding Sequence on DE Girth Weld, Step 1

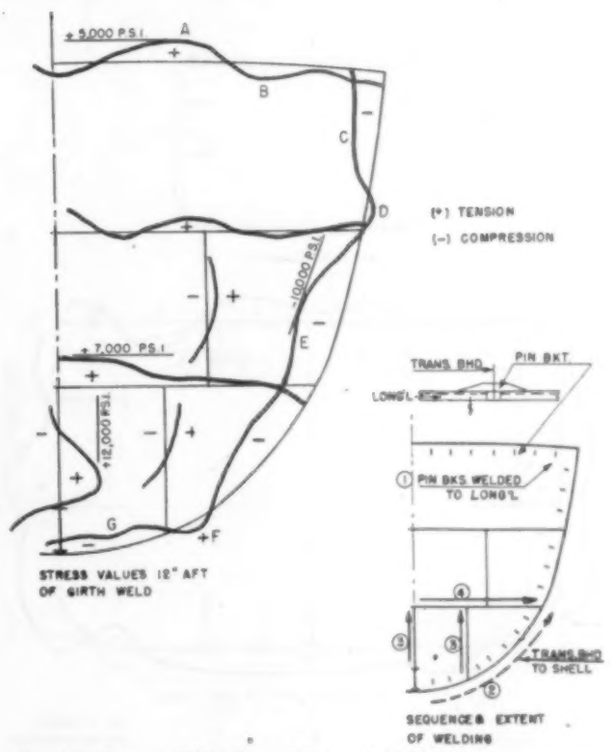


Fig. 18—Fore-and-Aft Stress Plot and Welding Sequence on DE Girth Weld, Step 2

during this test that would in any way interfere with the yard production schedules.

Prior to the welding of the girth butt the erection of the ship had reached the following stage: the entire aft end was erected and welded except the center line sections of the main deck over the machinery spaces. Forward of the girth butt all the shell was erected and welded including the bow unit. The main deck sections adjacent to the girth weld were in position and welded and the next section forward was in position and tacked with substantial tack welds. The remainder of the main deck was erected but not fitted or tacked. The first and second platforms and longitudinal bulkheads both forward and aft of bulkhead No. 47 were in position and welded.

The welding was done in three steps. First, the entire girth weld was made—shell and main deck. The second and third steps consisted of welding the internal structure including shell and main

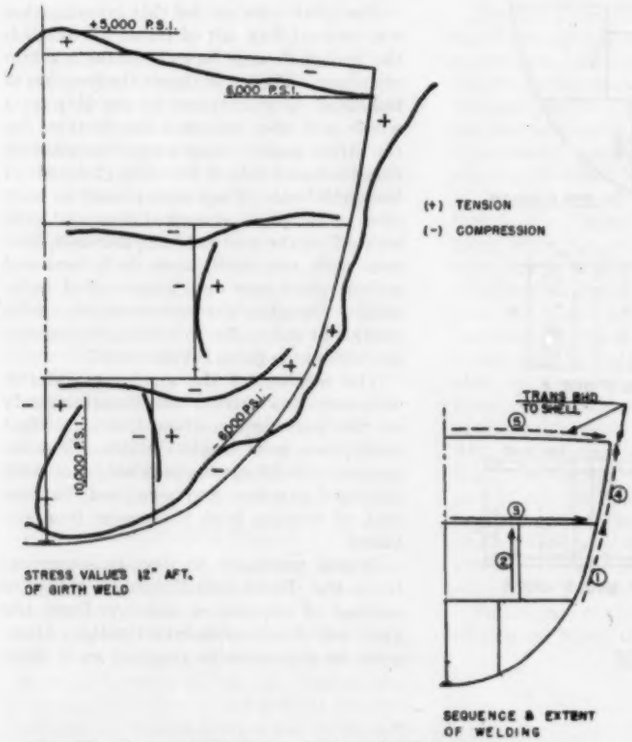


Fig. 19—Fore-and-Aft Stress Plot and Welding Sequence on DE Girth Weld, Step 3

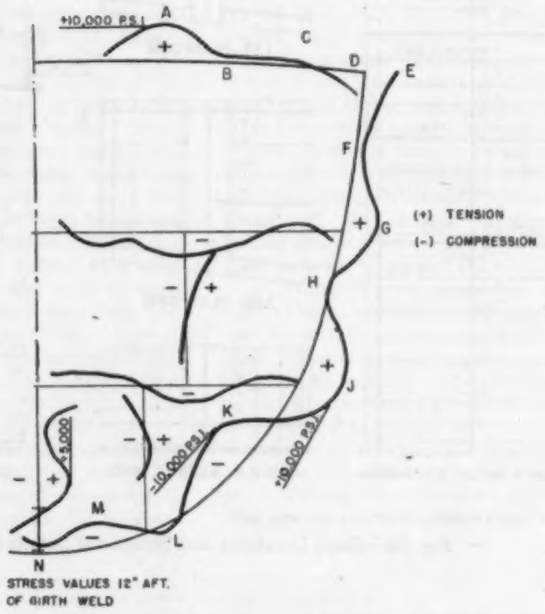


Fig. 20—Fore-and-Aft Stress Plot on DE Girth Weld, Sum of Steps 1, 2 and 3

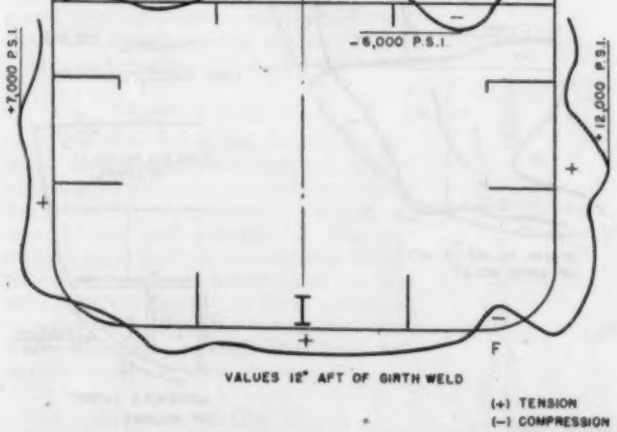


Fig. 21—Fore-and-Aft Stress Plot and Welding Sequence on DE Model, Step 1

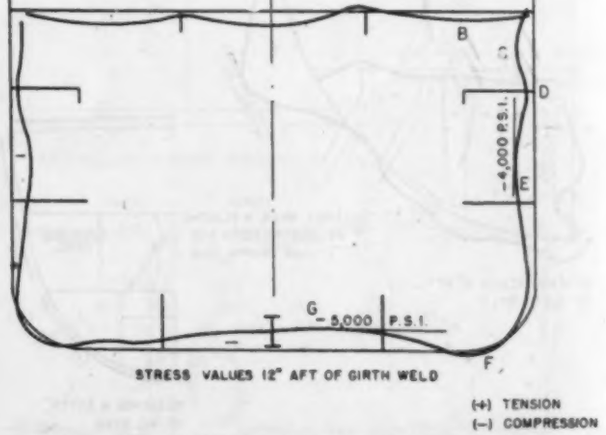


Fig. 22—Fore-and-Aft Stress Plot and Welding Sequence on DE Model, Step 2

deck pin brackets, platforms, and longitudinal and transverse bulkheads.

A distinct and convenient stopping place for each step occurred at the end of each day for three consecutive days. Strain gage readings were recorded during each of the corresponding nights to minimize stresses due to temperature variation throughout the hull, which is requisite to good data.

Discussion of Destroyer Escort Test

In considering the results of the Destroyer Escort girth weld, it should be appreciated that the welding sequence used on this vessel was not intended to tie in with the formation of any particular stress pattern. Had the welding stress pattern been a basic consideration, the progress of individual welds on a single joint probably would have had to be controlled by a special block sequence. This was not done since the introduction of such a change might have interfered with the vessel's construction schedule.

Measuring of strains under shipyard conditions is far from ideal. Many factors such as local bending of plates, welding of temporary stiffeners and strong backs during erection of welding, etc., complicate the picture. The stability of the delicate electric strain gages may be affected by varying weather conditions. Thus, we would expect some questionable welding stress values. Therefore, it is reasonable to consider only the general stress patterns and not the individual stress values.

Step 1 consisted of completing the main deck and shell girth butt weld.

As shown to the right on Fig. 17, welding was started approximately simultaneously at four positions port and starboard. Arrows indicate the work of groups of welders and the direction of their progress. It is interesting to note that the welding was scheduled to start at the bottom of the ship and progress upward according to a predetermined sequence. However, when the welding first started at the bottom some tack welds broke loose in the upper shell and across the main deck. To prevent further loss of tack welds the upper shell and main deck were welded at approximately the same time as the lower portion. After the root of the girth weld was chipped out, a seal bead was run completely around the girth progressing from the bottom up.

Figure 17 shows that a stress pattern was resolved similar to that which would be expected. Basically, the welding of the shell generated tension in the shell and moderate compression in the tack-welded internal structure (tack welded to aft side of transverse bulkhead). The welding of the internal structure to the forward side of the transverse bulkhead did not bring about complete structural continuity through the bulkhead and hence did not develop any distinctive reaction stress in the shell. In general, the points where welding ceased, such as at the junction of the first platform to the shell, the second platform to the shell and the main deck to the shell, are the points of maximum stress. Also, these points are "hard" spots in the structure where little distortion can take place to help relieve stress. Attention is directed to the wide band of tensile stress in the shell between the first and second platforms with a peak of 15,000 psi.

Step 2 (Fig. 18) involved welding the longitudinal pin bracket, the transverse bulkhead to the shell below the second platform, the second platform and the two longitudinal bulkheads below it to the aft side of the transverse bulkhead.

The welding of the internal structure below the second platform completed the structural continuity which would then be effective in setting up reaction stresses elsewhere in the ship's structure.

The welding of the pin bracket connections should set the shell and main deck area in the vicinity of the butt weld into compression, but it is probable that tensile stresses are induced in the shell away from the butt weld.

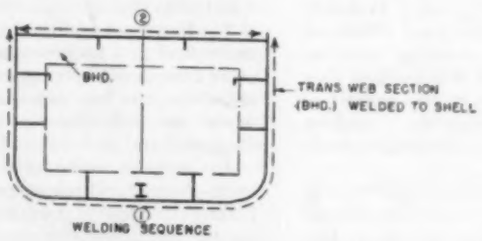
The subsequent welding of the transverse bulkhead to the shell would supposedly generate tension in the shell below the second platform; this tension was apparently small and overshadowed by the larger compression resulting from welding the pin brackets and the welding of the internal structure. Following this, the welding of the two longitudinal bulkheads and second platform would tend to build up tension in these structures and impose additional compression in the shell, especially the bottom.

The stress pattern in the entire internal structure is therefore an accumulation of tensile and compressive stresses, the welding of the pin brackets and transverse bulkhead creating compression and the welding of the remaining internal structure tending to create tension.

The delineation of the final stress pattern would depend not only on the welding sequence responsible for creating reaction stresses but also on the degree of restraint offered by the surrounding structure. The order of completion of the welding may well determine the location of the points of restraint.

Reference to Fig. 18 shows that the resulting stress pattern for step 2 seems reasonable with only a few exceptions. In general, the welding of the pin brackets has placed most of the shell and deck in compression. The welding of the second platform and longitudinal bulkheads has been effective in creating tension in these internal structural members and has probably accentuated the compression in the shell.

Step 3 completed the welding in the



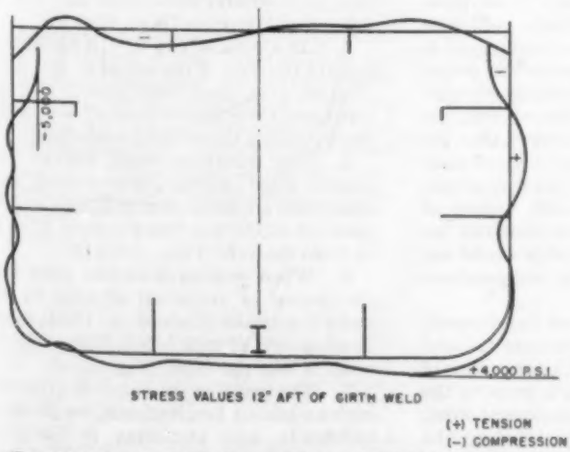


Fig. 23—Fore-and-Aft Stress Plot and Welding Sequence on DE Model, Step 3

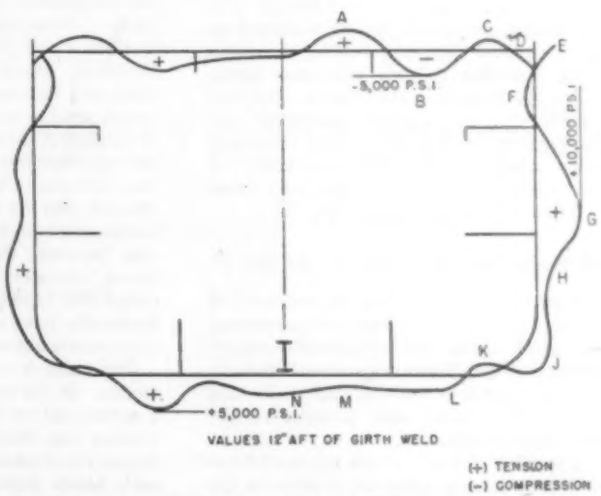


Fig. 24—Fore-and-Aft Stress Plot on DE Model, Sum of Steps 1, 2 and 3

vicinity of bulkhead No. 47. As shown at the right of Fig. 19 the internal structure above the second platform was welded to the aft side of the transverse bulkhead. The transverse bulkhead above the second platform was welded to the shell and main deck.

The welding of the bulkhead to the shell has created the anticipated tension in the shell, but there is a wide band of compression in the deck which suggests that the welding to the deck (*5*—Fig. 19) was completed prior to the welding to the shell (*4*—Fig. 19).

The welding of the internal structure between the first and second platforms has, as would be expected, created tension at the upper and lower edges of the longitudinal member and compression in the two platforms. Especially noticeable are the reaction stresses in the structure below the second platform where no welding was carried on.

Final Stress Pattern Developed by the Destroyer Escort Girth Weld

Figure 20 shows the final stress pattern which was obtained for the Destroyer Escort girth weld. This pattern is the sum of the patterns in steps 1, 2 and 3 (Figs. 17, 18 and 19). Figure 20 shows that, in general, tensile stresses were set up where the welding was completed or at "hard" spots which would be effective in generating peaks of reaction stresses. Particular attention is directed to the junctions of the first and second platforms with the shell. Shell welds and platform welds both terminated at this spot and the resulting high peaks of tensile stress are significant. It is also interesting to note that the welding of the internal structure, which is centered principally below the center of gravity, was effective in placing the lower part of the shell in compression.

Of most significance, however, is the fact that the Destroyer Escort behaved in a comparable manner to the model. The peaks of stress were generally of a similar order and in most cases the disposition of the zones of stress was in accordance with the principles demonstrated on the model.

Correlation of Destroyer Escort and DE Model Stress Patterns

An attempt was made to duplicate with the model the stress pattern obtained on the Destroyer Escort by welding the model with a similar welding procedure designated the Sequence DE Model. For this part of the investigation the model was modified to include a rounded bilge and some additional internal structure. A transverse section of the redesigned model is shown in the upper part of Fig. 21.

DE Model Sequence (Figs. 21, 22 and 23)

Step 1, as shown in Fig. 21, consisted of welding the shell butt, four sections around the girth being welded simultaneously. Because of size limitations, the shell welding was started at only two points instead of the three which were possible on the Destroyer Escort.

The effect of step 1 on the DE model was to create a fairly constant tension in the shell with four distinct peaks of compression—two at the turn of the bilge and two in the deck near the gunwale (*A* and *F*—Fig. 21, lower half). This stress pattern correlates fairly well with that obtained on the Destroyer Escort (Fig. 17). In both cases the result was fairly high tension in the shell with a tendency toward lower stress in two localized zones at the turn of the bilge and in the deck (points *A* and *F*—Figs. 17 and 21).

Step 2 consisted of welding the internal structure as shown in the upper section of Fig. 22. As would be expected, this has now placed the shell in fairly evenly balanced compression although it is interesting to note the minor peaks of tension at points *A* and *F* near the compression zones of step 1. Comparing Fig. 22 with step 2 on the DE (Fig. 18) again gives a good correlation. The stress patterns are almost identical—*A* through *G* being points of marked similarity in the two patterns.

Step 3 was to weld the bulkhead to the shell (Fig. 23, upper section). As would be expected, this welding has resulted in stresses which are predominantly tension in the shell although there are several zones of compression, notably at the gunwale and in the deck.

Comparison of Cumulative Stress Patterns—Destroyer Escort and Model

Comparisons of the cumulative stress patterns are not easy because of the inherent differences between the model and the ship. As mentioned previously, some differences existed in the welding sequences and there were inherent differences in the geometry of the two structures which it was realized would affect the delineation of the stress pattern.

In the model it was not practicable to build in complete bulkheads, longitudinals or platforms, because when these were reduced to $^1/_8$ scale, it would not be possible to work inside the structure. (Half of the gages were placed inside the model.) The rudimentary bulkheads, etc., probably served to create the localized effects of rigidity capable of creating reaction stresses in the shell, but it is unlikely that they were as effective in this respect as their full-scale counterparts. Making proper allowance for the above variables is difficult.

Figures 20 and 24 show that there is some similarity between the two stress patterns. To be sure, there are one or two stations where the agreement is not good. However, there is evidently sufficient similarity between the two structures to create similar zones of stress—the points *A* through *N* more or less corresponding on the two Figs. 20 and 24. In comparing the two patterns it will be observed that the stresses may be of opposite sign at some locations but at least there is some correlation between the peaks and valleys of stress. Greater geometrical similarity between the model and the ship would undoubtedly have resulted in configurations more nearly alike.

One point is evident from these experiments. In the original sequences 1, 2 and 3 carried out on the model, the progress of welding was clearly defined in steps by the deposition of blocks in chronological order, each block being completed before the welding progressed further along the joint. The block systems are effective in crystallizing definite zones of reaction stresses, and with these procedures it was possible to predict the form of the stress pattern in the model with some accuracy. On the ship, however, the progression of welding was not always so well delineated. Even though block welding was used, the order of completion of the blocks was not scheduled as precisely as was the case in the model and the effect of the blocks would be obscured somewhat by the seal bead in the root which would be "out of sequence." As a result the location of the focal points of rigidity which generate the reaction stresses was likely to be less determinate and with the technique employed on the ship, the shape of the stress pattern cannot be forecast with quite the same precision as was the case in the model experiments.

Conclusions

This paper does not claim to have discovered anything new regarding the control of welding stresses by the use of a controlled welding procedure. The advent of the resistance wire strain gage has, however, permitted the true delineation of residual weld stress patterns. This investigation has not changed, but rather it has confirmed, the concepts of residual weld stress patterns based on the logical evaluation of the factors involved.

The principal conclusion to be drawn is that the model and the ship yield comparable results, the peaks and contours of stress sharing similar characteristics. A large three-dimensional model scaled down from its full-scale counterpart should therefore be a reliable means of investigating residual welding stresses.

Even though the number of tests reported in this investigation is of necessity small, this work confirms several basic concepts regarding the development of welding stresses as follows:

1. Block welding creates a variable transverse stress in a welded joint (Figs. 6, 7 and 10 to 15).

2. In a block-welded joint, those blocks made first in a sequence are likely to resolve compressive stresses when the welding of the joint has been completed—those made last will develop tensile stresses (Figs. 6, 7 and 10 to 15).

3. In girth welds joining unrestrained three-dimensional subassemblies those portions welded first in a sequence are likely to resolve compressive stresses in the structure—conversely, those made last will develop tensile stresses (Figs. 10 to 15).

4. As a corollary of 3, it is possible to control the sign of the stress at any given location in a girth weld joining two unrestrained three-dimensional subassemblies by controlling the welding procedure.

5. The transverse weld stresses generated when joining unrestrained subassemblies are likely to be of a high order—peaks of 10,000 psi. being typical 12 to 21 in. from the weld (Figs. 10 to 15).

6. When welding a tacked girth butt the degree of restraint afforded by the tacks is considerable and can result in the development of wide bands of stress in the order of 3000–5000 psi. (Fig. 10).

7. The welding of internal structure such as joining longitudinals, longitudinal bulkheads, and platforms is likely to create tension in those members and compression in the shell (Fig. 18).

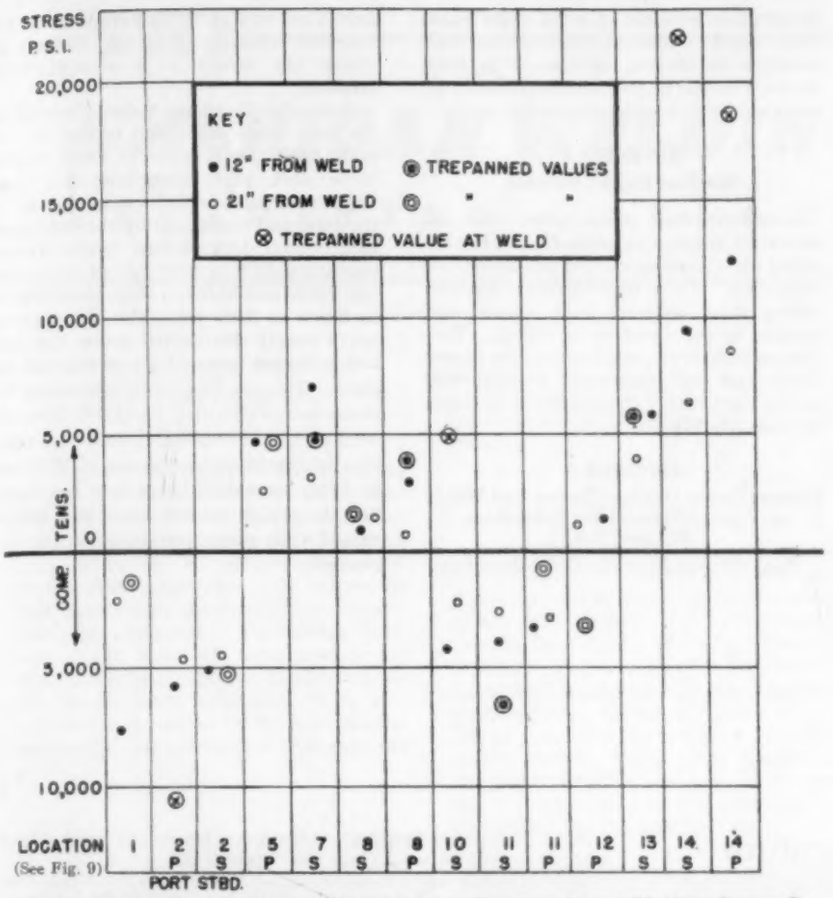


Fig. 25—Comparison of Fore-and-Aft Relaxation (Trepanned) and Welding Stresses in Girth Weld Model, Sequence 3

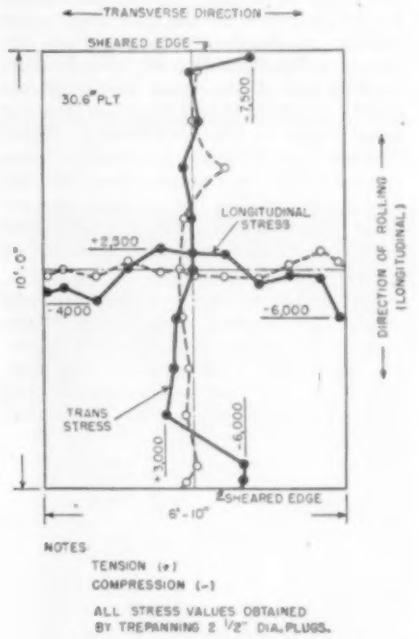


Fig. 26—Residual Rolling Stresses

8. Under conditions involving restraint, welding to the shell, such as welding a transverse bulkhead to the shell, is likely to create fore-and-aft tension in the shell and compression in the internal structure (Figs. 17 and 19).

9. In forecasting the stress resulting from welding, it is necessary to consider each step in the welding procedure particularly when successive steps may produce conflicting stresses.

Acknowledgment

A paper of this nature must of necessity reflect the work and cooperation of many individuals, therefore, the author wishes to acknowledge his indebtedness to various members of the Development and Research Department. Particular thanks are due H. G. Acker, Head of the Hull Research Section, who was in charge of these studies.

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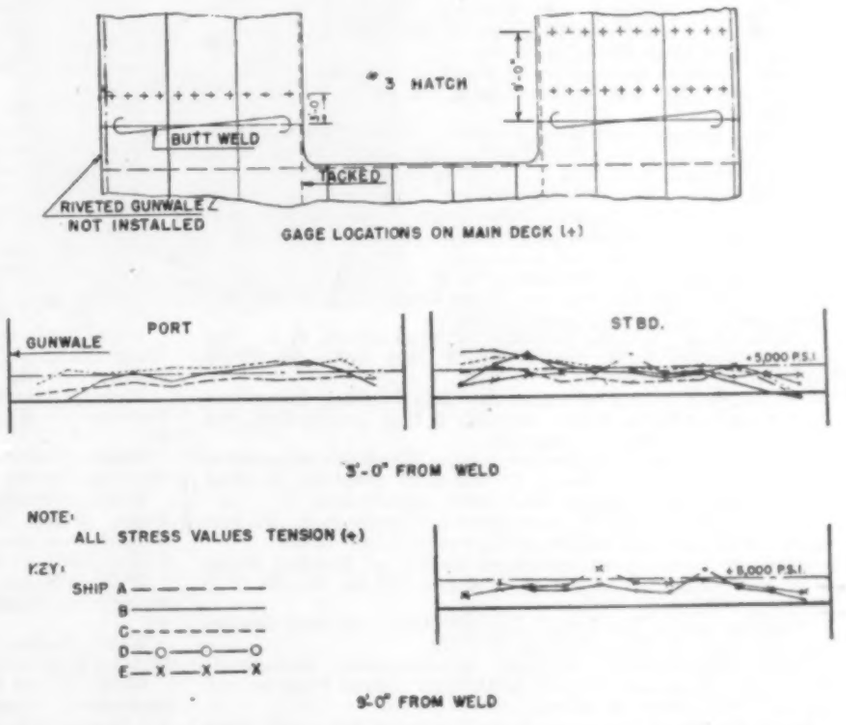

Fig. 27—Fore-and-Aft Stresses Due to Welding of Closing Butt on Beth-Fairfield Victory Ships

APPENDIX 1

Comparison Between Trepanned and Live Gage Values on Girth Weld Model

After sequence 3 was completed, eleven plugs were trepanned, nine from live gage locations, to compare the values obtained by relaxation with the live gage stress values. If complete stress relief was obtained by heat treating the model before welding and if the gages were perfectly stable, we would expect to obtain identical stress values by the two methods. Figure 25 shows that of the nine locations, only one showed a difference greater than 3000 psi. The variations for the majority ranged only from 1000 to 2000 psi., indicating good stress relief and gage stability at these places.

Of four plugs trepanned from the weld itself, three showed stress values of the same sign but somewhat greater magnitude than plugs at the same relative location but a short distance away from the weld. This would be expected. The usual longitudinal stresses of yield point value were found in the weld but are not indicated on the sketch. Stresses 12 in. from the butt should be greater than those 21 in. away, and this was found to be the case.

APPENDIX 2

Residual Rolling Stresses

Residual rolling stress values were obtained by trepanning plugs from a few as-rolled plates and measuring the amount of relaxation. These investigations revealed rolling stress patterns both normal and parallel to the direction of rolling. Tension up to 4000 psi. was found at the center of the plate and compression to about 6000 psi. at the edges. Typical stress patterns are shown in Fig. 26.

APPENDIX 3

Stresses Due to Making Closing Butt Welds on Victory Ships at the Bethlehem-Fairfield Yard

Tests conducted at the Bethlehem-Fairfield Yard on five Victory ships show that reaction welding stresses may be built up where the structure is somewhat restrained.

Fore-and-aft stress values (normal to the butt weld) are shown in Fig. 27. In main deck closing butts in which two or three deck plate assemblies had been welded together both forward and aft of the butt and restrained by the welding of longitudinal deck girders, tensile stresses averaging 3000 to 4000 psi. were recorded but variations between ships amounted to as much as 3000 psi. The stresses were fairly evenly distributed across the deck and extended fore and aft throughout the plate. This can be seen by comparing the stress values obtained 3 and 9 ft. from the weld on the same ship. Strain gage readings indicated tension zones of 8000 psi. in fairly large deck areas in a few cases, but these high tension zones were not revealed when plugs were subsequently trepanned.

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(*Continued from page 1108*)

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THE AMERICAN WELDING SOCIETY

ACTIVITIES — RELATED EVENTS

NEWLY ELECTED DIRECTORS AT LARGE

D. H. Corey

Don Corey was born in Winona, Minn., in 1900. He graduated from the University of Wisconsin with the degree of B.S. in Electrical Engineering, and has been employed by the Detroit Edison Co. since shortly after graduation. He started as Test Engineer in the Production Department, was advanced to Mechanical Engineer in the Research Department, and then to Welding Engineer, the latter position having been held since 1933, just prior to the adoption by the company of welding in the erection of high-pressure piping.

D. H. Corey

Mr. Corey is the author or co-author of several papers dealing with various aspects of the welding of piping for severe service conditions, delivered at Annual Meetings of the Society and before several Sections of the SOCIETY. He has served on numerous Society Committees, and is a Society representative on the American Standards Association Sectional Committee B-31, Code for Pressure Piping, and the Heating, Piping and Air Conditioning Contractors National Association's Editorial Committee. He was chairman of the committee which prepared Chapter 41A, Industrial Piping of the *Welding Handbook*. Mr. Corey served as Secretary Treasurer, Vice-Chairman and Chairman of the Detroit Section of the AMERICAN WELDING SOCIETY.

* * *

J. F. Maine

J. F. Maine has been associated with the fabrication of iron and steel since 1908. After graduating from the public school system of Cleveland, he entered the Engineering Department of Variety Iron and Steel Co. Further education was obtained by attending classes at various colleges, including Case School of Applied Science. He later entered the employ of Republic Structural Iron Works as an Engineer in the Engineering Department. He has been the Chief Engineer of this company and its affiliates for the last 23 years.

J. F. Maine

Mr. Maine has been chairman of the Cleveland Section, serving two years. He has also been District Vice-President of the A.W.S., and at the present time is working with the City of Cleveland in order to get a new building code adopted permitting welding.

He is a Registered Professional Engineer in the State of Ohio.

* * *

E. L. Mathy

Mr. Mathy was born in 1893 in Germany. He attended the Imperial Military Academy, and later the University of Breslau, where he specialized in chemistry and engineering. He has lived in California since 1912. He has been connected in one way or another with the welding industry for the last 30 years. In early days he was instrumental in the manufacture and sale of torches and regulators. He was connected with the Air Reduction Sales Co. from 1923 to 1927 as Pacific Coast sales representative. On January 1, 1928, he started with the Victor Equipment Company and is now its First Vice-President.

E. L. Mathy

Mr. Mathy is a member and a Past-President of the San Francisco Sales Managers Association; Past-President of the Industrial Advertisers of Northern California; Director of the International Acetylene Association and Past-Chairman of the San Francisco Section of the A.W.S. He belongs to the San Francisco Commercial Club, the Commonwealth Club of California and the Orinda Country Club. Mr. Mathy is in charge of the publicity and advertising for the Victor Equipment Co. One of his hobbies is photography.

* * *

Leslie S. McPhee

Leslie S. McPhee, born Feb. 22, 1904, started with the Whiting Corp. at Harvey Ill., Feb. 1920, as their first "Co-Op" Engineering Apprentice, going to school part of the day and working the rest of the day in the Shop Manufacturing and Fabricating Depts.

In 1924, he went into the Engineering Dept. as a draftsman taking I.C.S. Mechanical Engineering. In 1927, he was made Engineering Representative in the

L. S. McPhee

plant to coordinate engineering and manufacturing and expedite the correction of engineering errors and improvement of design throughout the plant.

Realizing the potential of welding relative to design, Les began to make a study of what was then mostly bare rod welding, getting the practical application side in the plant and the theoretical aspects at Armour Institute.

In 1933, Mr. McPhee was placed in charge of all welding and cutting operations. In view of the variety of products manufactured by the Whiting Corp.—heavy machinery, overhead cranes, foundry equipment, railway equipment, chemical equipment, metal working machinery, pulverizers, aviation equipment and special machinery—Mr. McPhee's experience is quite varied to include the fabrication of lead, copper, nickel, stainless steel, Monel, Inconel and Everdur, as well as the straight carbon steels fabricated both manually and by the automatic metallic arc processes.

Mr. McPhee is Past Chairman of the Chicago Section of the AMERICAN WELDING SOCIETY, past Vice-Chairman of the Mid-West Section of the AMERICAN WELDING SOCIETY, and Vice-President of the Chicago Technical Societies Council, Board of Directors Electronics Conference.

VICE-PRESIDENT DISTRICT NO. 2 (MID-EASTERN)

Harry W. Pierce

Harry W. Pierce

Harry W. Pierce was born in Syracuse, Neb., Sept. 30, 1901. He was graduated from the U. S. Naval Academy in 1922, commissioned Ensign, U. S. Navy, and served two years in Destroyer Squadrons, Battle Fleet. He was transferred to the Construction Corps, U. S. Navy, in 1924, and was ordered to postgraduate instruction at the Naval Academy and Massachusetts Institute of Technology, receiving the M.S. degree in Naval Construction in 1926. Following duty at the Philadelphia Navy Yard as Assistant Hull Superintendent, and as Assistant Superintending Constructor, U.S.N., at the plant of the New York Shipbuilding Corp., he resigned in 1930. Since October 1930 Mr. Pierce has been with the New York Shipbuilding Corp. in various capacities: Assistant General Foreman, Hull Dept.; Welding Supervisor, Welding Engineer and, at present, Assistant to the General Manager.

Since 1931 he has been principally occupied with welding development in ship construction, including design, specifications, procedure control and training. He served on numerous committees involved in the investigation of ship fractures and the research projects which resulted from those investigations during World War II.

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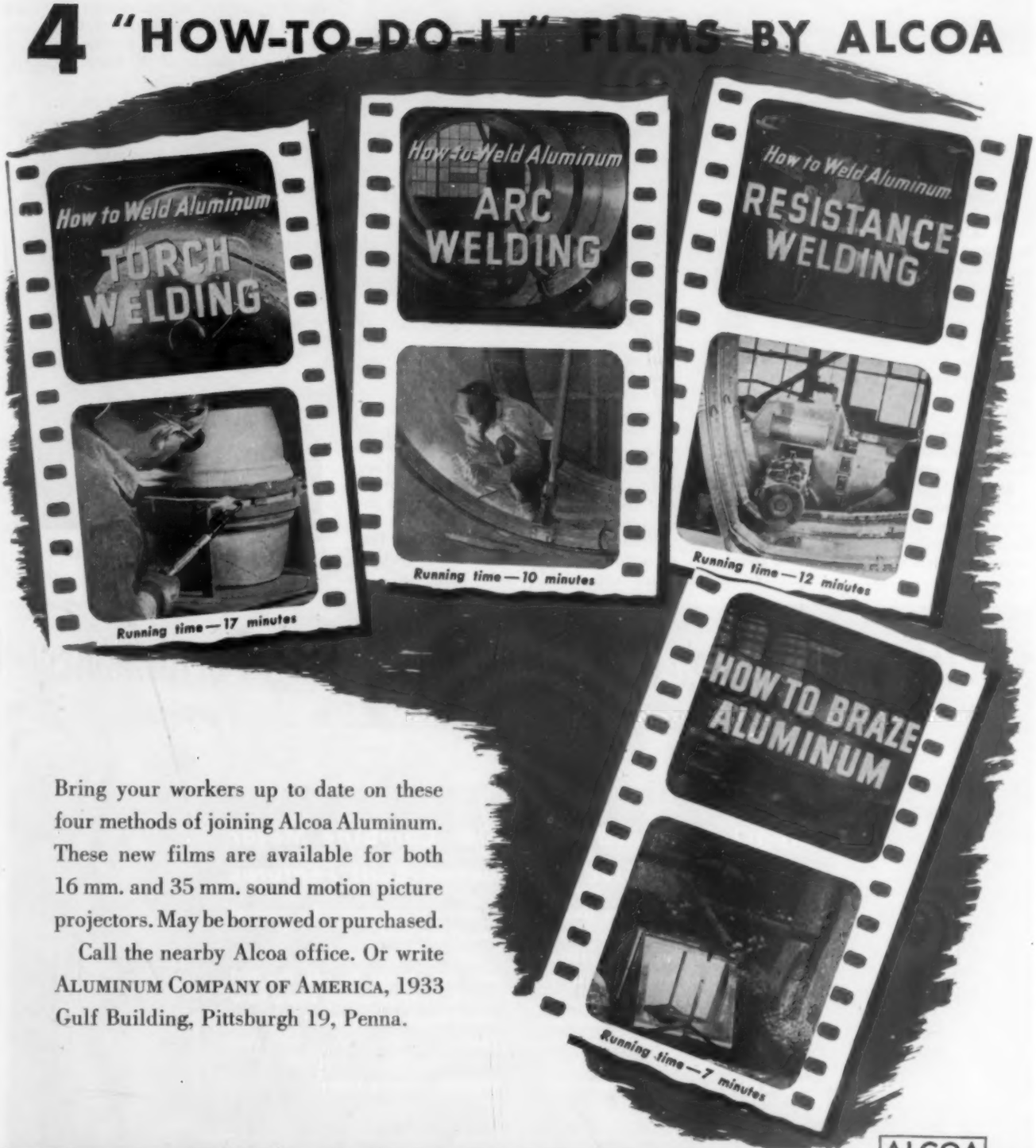

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He is a member of the Society of Naval Architects and Marine Engineers and the AMERICAN WELDING SOCIETY. He has presented various papers before both societies, and has served on several committees. Mr. Pierce served as chairman of the Philadelphia Section of the A.W.S. from 1942 to 1944. He is chairman of the Marine Committee and of the Technical Activities Committee of the A.W.S.

VICE-PRESIDENT DISTRICT NO. 4 (CENTRAL)

G. O. Hoglund

G. O. Hoglund, Welding Section Head of the Jobbing Division of Aluminum Company of America, is a native of Milwaukee, Wis. After attending that city's primary and preparatory schools, he studied aeronautical engineering at the University of Michigan, and was graduated in 1925 with a Bachelor of Science degree.

For the next two years Mr. Hoglund worked in the Bureau of Aeronautics, Navy Department, in Washington, D. C., designing airplane propellors. His next position was at the Naval Air Station in Lakehurst, N. J., after which he went to the University of Minnesota where he served as assistant professor of aeronautics during the college term of 1927–28.

Mr. Hoglund first became affiliated with the Aluminum Company in 1928 and for the next two years was employed in the Central Metallurgical Division. In 1930 he was transferred to the Job Shop to take

G. O. Hoglund

charge of the development of welding processes for aluminum.

During his period of service with the company, Mr. Hoglund has made many outstanding contributions to the progress of the aluminum industry. Through his efforts the techniques of resistance and arc welding of aluminum have been improved and their use expanded. He is also responsible for the initial work on the development of brazing processes as applied on aluminum alloys and holds brazing sheet patents in the United States, Canada Great Britain and South Africa.

Mr. Hoglund is the author of a number of technical articles which have appeared in the *SAE Journal*, *Mechanical Engineering* and THE WELDING JOURNAL. He is also very active in the AMERICAN WELDING SOCIETY, serving as a member of the Filler Metal Specification Committee, Chairman of the Subcommittee on Aluminum Brazing, and Chairman of the Society's Pittsburgh Section.

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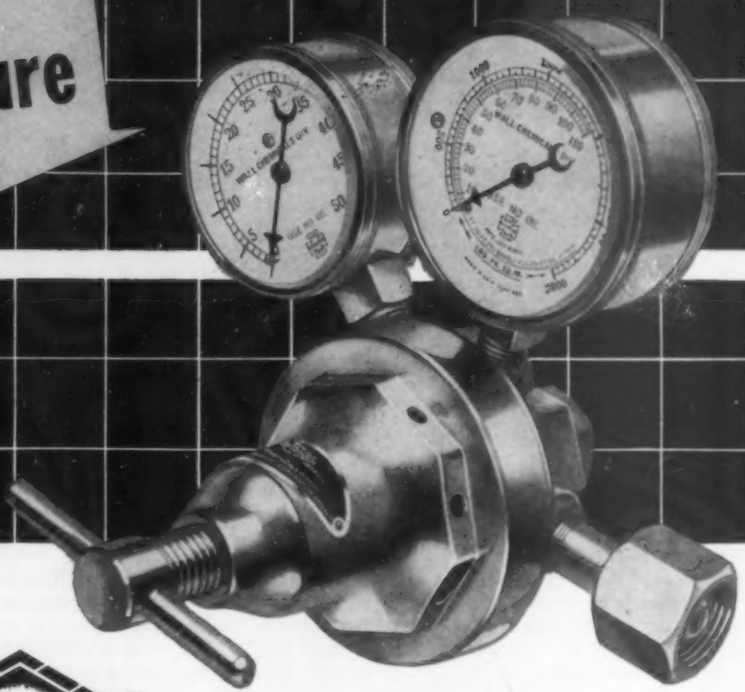

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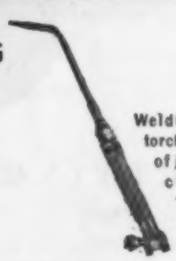

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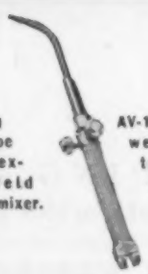

AV-10—Special lightweight AIRCRAFT torch for welding aluminum and light-gauge metals.

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VICE-PRESIDENT, DISTRICT NO. 6 (MID-SOUTHERN)

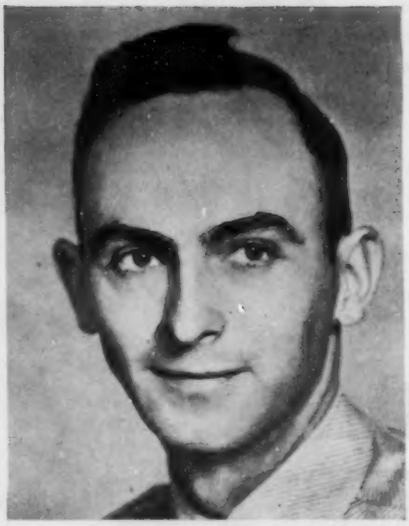
Howard W. Simms

Mr. Howard N. Simms is metallurgist with Black, Sivalls & Bryson, Inc., manufacturers and distributors of tanks, separators, walkways and welded vessels. Mr. Simms is concerned with the welding operations in all phases of this work. He has been active in the AMERICAN WELDING SOCIETY for the past several years. He is a past-chairman of the Oklahoma City Section.

FIRST AWARD WINNER IN DIVISION ONE OF THE LINCOLN AGRICULTURAL AWARD AND SCHOLARSHIP PROGRAM

Elgar Schroeder, the 27-yr.-old Morrisonville, Wis., farm youth, whose paper on "the benefits of arc welding on my farm" won him top honors in division one of the Agricultural Award and Scholarship Program, sponsored by the James F. Lincoln Arc Welding Foundation, typifies the new era of American agriculturists.

As a result of his early realization of the importance of mechanized equipment to modern farming, and the ability to tell the story of how this equipment has helped him toward success, he recently received a cash award of $3284.70 and the honor of sponsoring six agricultural scholarships in his former alma mater, the College of Agriculture of the University of Wisconsin. The six scholarships, valued at $250 each, will be presented to the university by the Arc Welding Foundation in Mr. Shroeder's name.



Elgar Schroeder

Mr. Schroeder was one of hundreds of agricultural producers who participated from all parts of the nation in the Foundation's $37,500 Award and Scholarship Program.

Elgar and his father operate a 130-acre farm in Morrisonville and are primarily engaged in the raising and fattening of baby beef cattle of the angus-shorthorn cross variety. Elgar was born April 4, 1919, an only child. He grew up on the farm he now helps his father operate, obtained his education in the local grade and high school and entered the College of Agriculture of the University of Wisconsin in 1937.

After a year of study, his education was interrupted. His help was needed on the farm. He has continued his studies, however, through the High School Vocational Agriculture Department at DeForest, Wis., and the extension services of the nearby College of Agriculture at Madison.

"My 130-lb. physique soon forced me to the realization that any future for me in farming must depend on mechanization," declares Mr. Schroeder. "I was of the opinion that a small farm could be as successfully mechanized as a large commercial type farm if the operator were judicious in the purchase of machines of the proper size and if their price tags were companionable with his resources."

Mr. Schroeder, in connection with the operation of his father's farm, not only realized the potential value of the small, efficient machines which were available on the mass market, but he was cognizant of the value of used machines which could be purchased at correspondingly lower prices and repaired economically during off-season lulls.

It was in connection with these repair activities and the building of simpler machinery in his farm shop that Mr. Schroeder first became interested in arc welding.

"Vaguely familiar with the potential benefits of arc welding, I shared the misinformed opinion of many that it was too

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. . . with special controls and operating features that make better welding easier—indoor or outdoor, 100 to 1000 amps. Inert-Arc and Atomic-hydrogen welding equipment, engine-driven sets, and automatic machine-welders are also included in the G-E line.

ELECTRODES

Headed by the *new* W-20 general-purpose electrode (this single electrode meets 60% of industry requirements), the G-E line-up includes general and special-purpose rods, production-tested and -labeled, for almost any metal or application—and all *available for immediate delivery*. Why not sample a few?

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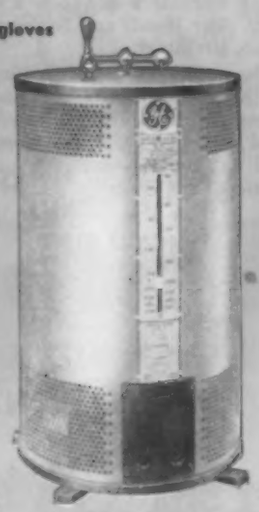
Twenty-four to 48-hour service is available on orders for most G-E accessory items—all built for added protection and longer life. One of the most complete lines available, it includes ventilated helmets and hand-shields, electrode holders, protective clothing of all types, and Strike-easy and weld-spatter-resistant compounds.

Your nearest G-E Arc-welding Distributor is waiting to service your welding requirements. See him, 'phone him, or write him! *Apparatus Dept., General Electric, Schenectady 5, N. Y.*

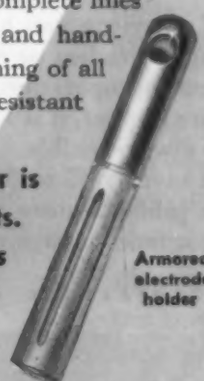
Welder's gloves

Ventilated helmet



300-amp a-c welder

Single-operator, portable d-c welder, 300-amp model



Armored electrode holder

VISIT US AT THE NATIONAL METALS SHOW

Coming to the National Metal Congress and Exposition in Atlantic City November 18 to 22? If so, be sure to plan on a visit to the G-E Welding Booth. You'll find the several operating exhibits (Inert-Arc welding of aluminum, newest techniques and developments with the latest type electrodes, etc.) mighty interesting.

GENERAL ELECTRIC

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difficult and too expensive for my use, "he declares. "But when the National Defense Schools offered a welding course in my home town garage, I was among the first to enroll. I quickly mastered the skill and, as soon as possible, made the thrifty purchase of a small welder. It has been profitable."

The Schroeder farm is now equipped with a tractor and attachments, a small combine, a single row corn picker, a garden tractor for delicate row crops and a power lawn mower. Home constructed labor savers include a corn-grain electric elevator, a grain windrower, a cultipacker seeder and many smaller pieces of equipment.

Some of the Schroeder machinery was purchased new and is carefully maintained to keep it in fine condition. Other pieces had been used when purchased and were restored to good condition by repair. Some were entirely rebuilt.

"In each case," Mr. Schroeder continues, "the purchase was very carefully considered so that time and repairs spent on each machine would show a margin of profit. War Bonds and Savings were religiously left intact.

"The yield of crops and fertility of soil, as well as quality of livestock has steadily improved as mechanization eased the burden of labor and there was more time released to keep the machinery in proper condition.

METCO NEWS

The October issue of *METCO News*, published by Metallizing Engineering Co., Inc., Long Island City, New York, tells how metallizing (metal-spraying) did the following: (1) Cut from $6598 to $1393 the cost of replacing a rudder stock liner, saving much handling and doing a 6-day job in 26 hr. (2) Saved $1500–$2000 in the restoration of main bearing journals of a large ammonia compressor. (3) Gave spherical surfaces better wearing qualities (in this case, locomotive "booster balls"). (4) Avoided a three-week shutdown of a main boiler system by rebuilding in 50 hr. the worn section on the shaft of an induced draught fan. (5) Re-conditioned a 1500-hp. horizontal turbine by building back to original size the bronze seal rings, water vane shafts and bucket corners. (6) Solved the problem of corrosion prevention in 36-in. air valves of a lighter-than-air craft. A technical article describes the reduction of grain growth in plain cast iron subject to high temperatures, through the use of METCOLIZING (a special metallizing process).

H. N. EWERTZ HEADS McKAY ELECTRODE SALES DIV.

The appointment of Harold N. Ewertz as Sales Manager of the Electrode Div. of the McKay Co. was recently announced by Fred C. Smith, General Sales Manager.

Mr. Ewertz, during his entire business career, has been associated with the welding industry. From 1938 until 1944 he was Sales Manager of the Arcos Corp. where he organized the Philadelphia sales force and helped develop a national distribution organization. Prior to 1938, he was Welding Engineer and Sales Manager of Austin-Hastings Co.

Harold N. Ewertz

A graduate of Massachusetts Institute of Technology, Mr. Ewertz is widely known in welding circles. As an active member of the AMERICAN WELDING SOCIETY, which his father, Eric Ewertz, helped found, he has been Chairman of the Boston Section, a member of its Executive Committee and National Vice-President for New York and New England.

Mr. Ewertz, during the war, served in U. S. Army Service Forces, Ordinance Department, Ferrous Metallurgical Advisory Board Subcommittee on Welding Armo .

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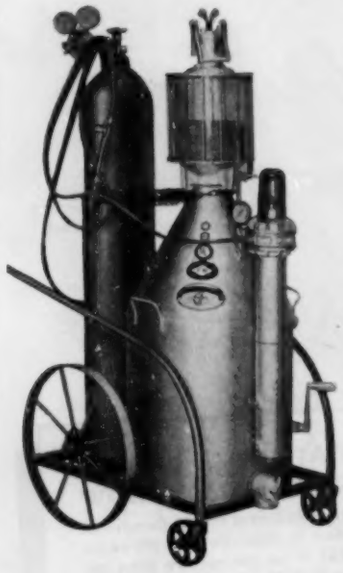

● You won't run out of acetylene if you have a Sight Feed Acetylene Generator. A glance at the hopper will tell you instantly how much acetylene you have available.

As a user of acetylene you know it is wasteful of both time and money to change cylinders or recharge a generator in the middle of a welding or cutting operation. Sight Feed's hopper eliminates this loss. Look at the hopper, it is Pyrex, you look through it, not into it. The carbide is always visible.

A Sight Feed saves 50% to 75% on acetylene costs.

Stop at your jobber's store and have him demonstrate the Sight Feed or write for free 16-page catalogue No. 44-G.

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What will these New Alloys do for you?

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See EASY-FLO 45 and 35 at work on actual production jobs. Examine the large collection of parts and products now made with low-temperature silver alloy brazing. See how others use fast handling and heating methods to boost production. Discuss your metal joining problems with our field engineers who will be on duty at all times. If you attend be sure to stop at Booth F-147.

—THAT'S THE QUESTION

We can tell you how lower flow point, lower silver content, faster spreading action and small amount of alloy save time and reduce costs. We can tell too, of tests that have won wide approval for these new alloys in the field. But if you want quick action, if you want to start saving and speeding-up NOW, try EASY-FLO 45 and 35 on your own work in your own plant. Ask **your regular supplier** for a free demonstration . . . or better still if you are familiar with this metal joining method place a trial order with him and put these alloys to your own tests on actual jobs.

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ORGANIZATIONS OF ENGINEERS IN THE UNITED STATES OF AMERICA

An excellent paper on the above subject was presented by C. E. Davies, Secretary of The American Society of Mechanical Engineers, at the International Technical Congress in Paris, September 16–21.

Mr. Davis, in his usual excellent style, reviewed how the engineer arranges his professional life. He gave some vital statistics on the number of engineers, engineering students and engineering associations in the U.S.A. He outlined a general program of professional responsibilities and the corresponding purposes of engineering societies. He indicated how engineering societies act jointly in matters of mutual and public interest.

J. D. ZAISER BECOMES PRESIDENT, AMPCO METAL, INC.

J. Donald Zaiser was elected President and General Manager of Ampco Metal, Inc., Milwaukee 4, Wis., on August 23rd, succeeding his father, C. J. Zaiser, who passed away July 29th.

The new Ampco President has been associated with the company since 1933 when, after graduating from Purdue University with a Mechanical Engineering Degree, he joined Ampco's Production Dept. A year later he transferred to the Field Sales Dept. and became department manager in 1936.

He became General Sales Manager in January 1938; Vice-President and Assistant General Manager in October 1940; Executive Vice-President in March 1944 and was appointed General Manager in March 1945.

Mr. Zaiser worked closely with his father in developing the company from a small foundry, casting copper base alloys by sand and centrifugal methods, to the biggest producer of special bronze alloys in the country. During World War II the company had 2700 employees and its gross income was $22,000,000 in a single war year.

J. Donald Zaiser

FULLMAN RETIRES

J. M. G. Fullman retired on August 31st as general design engineer of National Electric Products Corp., Pittsburgh, after completing more than 33 years' service with the company, of which more than one-third was as works manager of the Ambridge, Pa., plant.

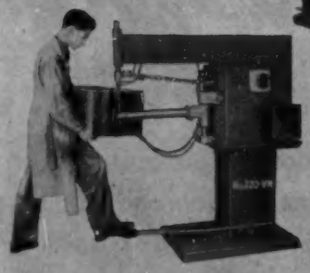
Previous to joining the National Electric organization in 1913, Mr. Fullman had been an electrical contractor and a manufacturer of electrical roughing-in materials.

He served for more than ten years as National Electric works manager and in 1927 was appointed general design engineer. In the last 19 years he has made many important contributions to both National Electric plant equipment and products. Numerous patents have been granted to Mr. Fullman, which he assigned to the company.

During his affiliation with National Electric, Mr. Fullman has been a member of the American Society for Metals, the American Institute of Electrical Inspectors, American Society for Testing Materials and AMERICAN WELDING SOCIETY. He is a member of the Engineers' Society of Western Pennsylvania. Mr. Fullman has been active in Masonic circles and is a member of the Town Council of Sewickley, Pa., where he and Mrs. Fullman reside.

James B. Fullman, a son, is an architectural representative in New York City for A. M. Byers Co., and Robert L., another son, is a research metallurgist for American Smelter and Refining Co., Perth Amboy, N. J.

SPOT • BUTT • ARC
WELDERS



AIR, FOOT or MOTOR Operated Press Type Welders of All Sizes.

We manufacture a complete line of resistance spot welders from ¼ to 300 KVA for all types of welding. There is an EISLER WELDER for every purpose.

Transformers of all types.

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The new versatile Oakite Compound No. 34 helps provide cleaner surfaces for better work on such jobs as: deoxidizing aluminum alloys before spot welding or anodizing; removing oxide from brass; stripping anodized film from aluminum; obtaining smut-free etched surface prior to painting.

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The answer is: not *what* you do, but *how* you do it.

Suppose we take as simple a thing as assembling a metal drawer. You can do it any number of ways. You can rivet, use nut and bolts or some other fastening device, or you can arc-weld (with expert operators). In any event there is a lot of manual handling of the work. Other operations—such as drilling—may be required, and the job takes time: man hours and machine hours.

Or-you can resistance-weld

At the left is a typical Progressive designed-to-the-job machine which automatically assembles a drawer every 15 seconds, making as many as 48 spot welds in each one. All the operator does is drop the parts in place, throw a couple of light toggle clamps and *push a button.*

The result?

The manufacturer keeps his costs and price down. The shop produces more. The worker can justify his high wages while actually doing less physical work.

And the product has been improved!

This is not a special case. It's happening all over the country on all kinds of products. Progressive's ability to design and build the kind of equipment that cuts your costs is what has made it the leading producer of resistance welding equipment today.

We will be glad to study your product from the standpoint of its weldability at lower unit costs.

Are you receiving the Progressive Pictorial? It will bring you regularly the latest news on resistance welding design, methods and equipment.

SEE US AT THE METALS SHOW—BOOTH No. J-220

IT PAYS TO WELD

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RESISTANCE WELDING EQUIPMENT

CABLE ADDRESS "PROGWELD"

MEMBER RWMA

CARY JOINS BATTELLE

Howard B. Cary, a graduate in welding engineering from Ohio State University has joined the staff of Battelle Institute, Columbus, Ohio, and will be engaged in research in controlled atmosphere welding and aircraft tube welding.

Prior to joining the Battelle staff, Mr. Cary was a process engineer with the Fisher Body Div., Detroit, Mich. He is affiliated with the AMERICAN WELDING SOCIETY.

ROBERTS OPENS OFFICE

Charles Roberts, member of the AMERICAN WELDING SOCIETY, and a registered architect, opened up a new office at 539 N. Homewood Ave., Pittsburgh 6, Pa. Mr. Roberts has been connected with the building industry for twenty years and is a great advocate of welding in all its phases.

GULVIN WINS LINCOLN AGRICULTURAL AWARD

Harold E. Gulvin's widespread experience in the application and teaching of arc welding and his ability to compile a comprehensive report on those activities, brought him the first place cash award of $3964 as top winner in division two of the Agricultural Award and Scholarship Program, sponsored by The James F. Lincoln Arc Welding Foundation.

In addition to the cash award, Mr. Gulvin will also have six agricultural scholarships, valued at $250 each, presented to his alma mater, Cornell University, by the Foundation under his name. These will be known as "the Harold E. Gulvin Scholarships of the Lincoln Foundation."

Harold E. Gulvin

The paper which won these honors for him contained 170 pages of information on "Arc Welding on the Farm," including 111 illustrations and data on the servicing, repair and construction and rebuilding of a wide variety of farm equipment and the farm shop he has built largely by welded fabrication.

Mr. Gulvin was born and raised in the Finger Lake region of New York State, studied vocational agriculture in high school and majored in agricultural science at Cornell. He obtained his Bachelor of Science degree in 1930.

He began teaching vocational agriculture at Ellington, N. Y., immediately after obtaining his degree and continued to do so until 1936 when he transferred to Forestville.

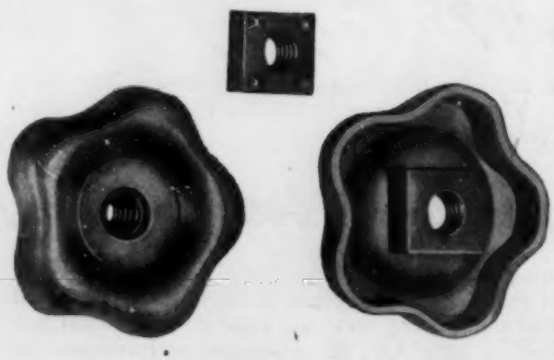
Mr. Gulvin was married to Alice Horner in 1931 and the couple have three children, Majorie, 14, David, 11, and Darlene, 6.

Since 1941, Mr. Gulvin has been engaged in one of the most extensive training courses on farm machinery in the United States. This includes showing farmers how to repair, maintain and construct farm equipment, including tractors. Classes having included as many as 100 farmers. He has also built a school shop building, several brooder houses, rearranged several dairy barns, laid out drainage systems and completed numerous wiring jobs. His many activities have brought Mr. Gulvin recognition as one of the outstanding teachers of farm boys in New York State.

In addition to his formal education at Cornell, Mr. Gulvin also received his Master of Education degree at the University of Buffalo this year.

His extensive paper presented in the Foundation's Award and Scholarship Program was outstanding among the hundreds submitted by agricultural producers, educators and service officials from all parts of the nation.

Ohio Weld Products
for projection welding



This large adjusting nut made by welding an Ohio Square Weld Nut to a stamping, illustrates one of the many applications where Ohio Weld Products help increase production and reduce cost. The welding is done on Standard Press Welders.

Send for samples and further information to:

THE OHIO NUT & BOLT COMPANY
626 N. Front Street, Berea, Ohio

TIP CLEANING DRILLS
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BRASS *Handled*

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Box 691, Albuquerque, N. M.

WANTED

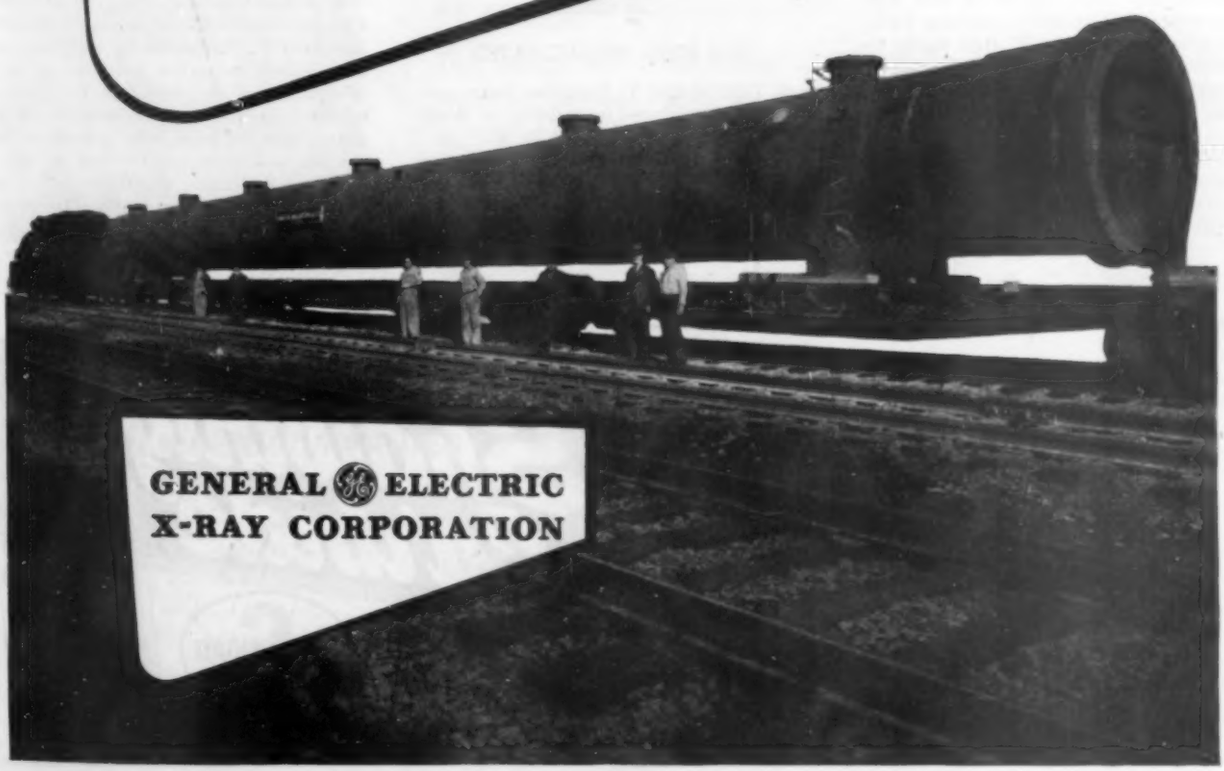
Two Jr. Electrical Engineers. Single men preferred. One for Electrical Transformer Engineering and one for Laboratory and Resistance Welding work to train as Resistance Welding Engineers. Write N. L. Pernice, Taylor-Winfield Corporation, Warren, Ohio stating education and experience.

ENDURANCE INSURANCE } Weld Inspection by G-E X-Ray

Somewhere in Pennsylvania a tube of steel . . . little more than 8 feet in diameter . . . thrusts skyward over 150 feet. It's a deisobutanizer tower—this 69-ton industrial monument—recently erected by a major oil company. Combustion Engineering Company fabricated the huge vessel in its Heine Boiler Division plant at St. Louis. To insure maximum structural strength, every inch of welded seam was G-E X-Ray inspected.

Long-time users of G-E X-Ray apparatus, Combustion Engineering employs numerous G-E industrial units in their several manufacturing plants. Two were used by Heine to inspect the 509 lineal feet of welding joining this great tower... a 220 and 400 kvp., for the girth and long seams respectively. Almost 500 films—4½- by 17-inch—were required to insure flaw-free weldment.

Industries with individual problems have long looked to G. E. X-Ray for solutions—and have found them. That same service is yours for the asking. Write or wire today, to General Electric X-Ray Corporation, 175 West Jackson Blvd., Chicago 4, Illinois, Department M81.



HEAT TREATMENT OF CARBON STEELS

This up-to-date book by F. Johnson, D.Sc., Head of Department of Metallurgy, Central Technical College, Birmingham, discusses in detail the various methods and apparatus used in the heat treatment of carbon steels, the effect of composition and heat treatment on the physical properties of the finished product, and the tests used for determining the physical constants and mechanical properties of steel. Over a hundred diagrams and illustrations and many helpful tables add to the value of this volume which will be of great interest to engineers using carbon steels, metallurgists and students of both engineering and metallurgy.

Contents: Composition. Effects of Carbon on the Properties of Iron. Influence of Carbon on Mechanical Properties. Phase-changes of Iron; Influence of Carbon thereon. Microstructures of Typical Carbon Steels, etc. Forging. Preheating. Normalizing. Annealing. Process Annealing. "Banded" Structure Control. Spheroidizing. Influence of Annealing on Microstructure. Hardening; Influence of Size of Section, etc. Hardening Penetration. Effects of Mass and Composition. Hardness—Penetration Diagrams, etc. Various Practical Tests for Hardenability. Use of Hardenability. Tests in Predicting Response of Emergency Steels to Hardening. Use of Hardenability Tests in Differentiating between "Heats" of Steel Similar in Composition, etc. Relationship of Crystallinity to Mechanical Properties, Ductile and Non-ductile Materials. Load. Strain. Stress. Structural Arrangement of Atoms. Elasticity, Plasticity. Elastic Limits. Limit of Proportionality, etc. Toughness. The Bend-test. Impact Tests. Charpy and Izod Methods. Influence of Non-metallic Inclusions. Hardness Tests; Brinell, Vickers, Rockwell. File-hardness Test. Bouncing Ball Test. Scleroscope. Hardness Conversion Table. Machineability Test. Molten Baths for Various Temperatures. Quenching Media. Interrupted Hardening. Graduated Hardening. Effects of Tempering Temperatures on Physical Properties. Annealing and Associated Oxide Film-colors. Main Reasons for Hardening Failures, etc. American Standard for Carbon and Alloy Steels, etc.

204 pages; illustrated; price $4.00.

J. C. LEONARD MADE SALES MANAGER

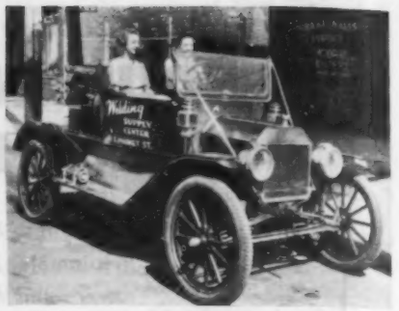
Announcement is made by Oakite Products, Inc., New York, of the appointment of J. C. Leonard as Sales Manager of its Industrial Marketing Division. Associated with the Oakite organization in the servicing of its specialized cleaning materials and equipment for over 22 years, the last 16 years of which was in the capacity of Manager of the Company's Chicago Division, Mr. Leonard assumed his new duties on Sept. 1, 1946. He will direct the marketing and servicing activities of Oakite's industrial field staff from the general offices of the company in New York.

J. C. Leonard

1910 FORD REHABILITATED

A 1910 Model T. Ford has been completely rehabilitated by welding by Welding Supply Center, Buffalo 4, N. Y.

This is a car used for parades and other civic gatherings to promote good will and keep the company name before the public. This has proved to be a definite asset, creating great interest, particularly to the younger generation, who have never seen these old buggies.



In hand-making a great many of the parts, which were totally worn out or disintegrated through time, welding played a major part in its rehabilitation. Today, it runs like a clock.

It doesn't even have a rattle. Whenever a rattle develops, Mr. Foley, the Manager, states they just weld the two rattlers together.

PATENT RESEARCH

Patent research is to become vastly more important according to Invention, Inc., Washington, D.C., patent research organization. Inventors, and manufacturers, too, may withold the details of their inventions until patenting and it is the established policy of the U. S. Patent Office to hold inventions strictly secret until patents are finally granted. This fact, and a postwar boom in invention, is causing the piling up of what may prove to be one of the nation's most valuable surpluses.

U. S. patents, numbered consecutively, are now being given numbers in the 2-million, 4-hundred-thousands. Invention, Inc., which serves industry with information on new technical developments, offers a pocket-sized folder entitled "Telling the Age of a U. S. Patent by its Number." This handy reference contains a dated tabulation of the numbers for patents, reissues, designs and trademarks for 110 years, from the year 1846 to 1946, so that age for a known number can be determined at a glance. The folder is free and may be obtained by writing Invention, Inc., Munsey Building, Washington 4, D. C.

Buy "Proven Fluxes" with Years of Guaranteed Satisfaction behind them
The Trade-Name is "ANTI-BORAX"

Ask for Them ***Unequalled for Quality***

A Flux for every metal: Cast Iron Welding Flux No. 1; Brazing Flux No. 2; Braz-Cast Flux No. 4 for bronze-welding cast iron; "ABC" Aluminum Flux No. 8 for sheet Aluminum and all alloys of Aluminum; Stainless Steel Flux No. 9; Silver Solder Brazing Flux No. 10; No. 16 Silver Solder Paste Flux.

ANTI-BORAX COMPOUND COMPANY

Fort Wayne, Indiana

Time Counts—
Gas cut and Weld with

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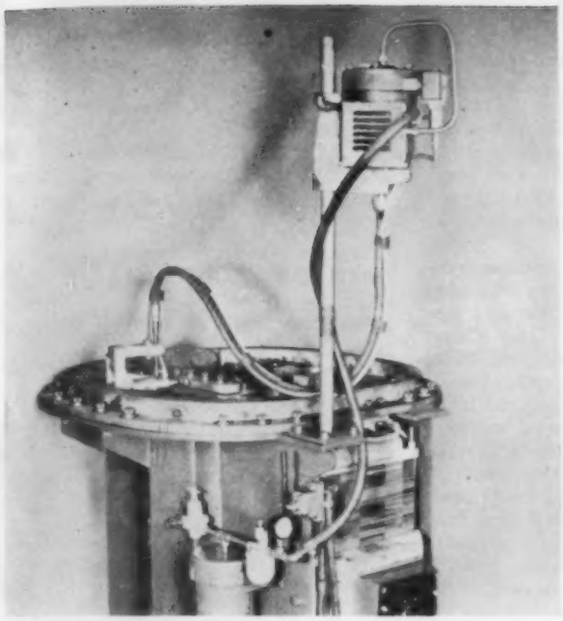
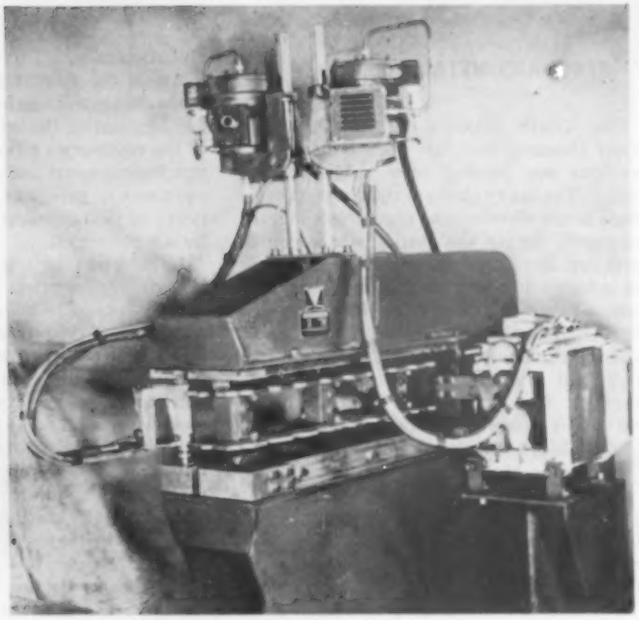
SHAWINIGAN PRODUCTS CORPORATION
EMPIRE STATE BUILDING, NEW YORK 1, N.Y.



Fixture for welding bottoms to shells with expansion type welding gun.



A two-gun welder with fixture for locating and spot welding. Fast production is assured on a variety of assemblies.

HOW TO KEEP WELDING GUNS "ON TARGET"

This type of fixture facilitates use of gun welder on awkward assemblies.

Spot welding guns simplify the problem of welding many types of large and cumbersome assemblies. The work remains stationary while these handy little machines can be moved around and put welds where you want them—quickly and at low cost.

Suitable fixtures as illustrated here make this a high precision process. Accurate positioning and correct spot spacing make for consistent weld quality and good appearance of the product. Uniform alignment with the work results in longer electrode life.

The design and construction of fixtures for every type of resistance welding, devices which speed production and improve weld quality, is one of the many services available from members of Resistance Welder Manufacturers' Association. If you have assembly problems which are difficult, it will pay you to consult them.

RESISTANCE WELDER MANUFACTURERS' ASSOCIATION
505 Arch Street ● Philadelphia 6, Pa.

MEMBER COMPANIES OF RWMA

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Detroit 4, Michigan
Welding Sales & Engineering Co.
Detroit 13, Michigan
Ampco Metal, Inc.
Milwaukee 4, Wisconsin
Commerce Pattern Foundry & Mach. Co.
Detroit 17, Michigan

STANDARD METAL DIRECTORY

The Tenth Edition of the *Standard Metal Directory* has just been issued, the previous one having been published in 1943. The many changes that have taken place in the ferrous and nonferrous metal industries during the war, made a complete revision of the old edition necessary. All information has been brought up-to-date. There are more than 842 pages in the 1946 edition—an increase of 150 pages over the previous edition. The Directory is divided into four special sections embracing: Iron and Steel Plants, Ferrous and Non-Ferrous Metal Foundries, Metal Rolling Mills, Smelters and Refiners of Non-Ferrous Metals.

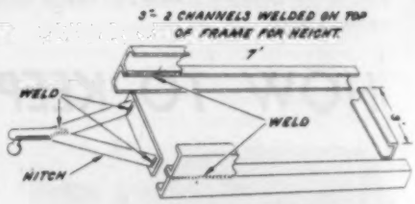
The Directory contains more than 7000 detailed reports on steel mills, ferrous and nonferrous metal foundries, metal smelters, metal rolling mills and nonferrous plants in the United States and Canada. The plants are listed geographically and alphabetically. The reports give the name of the company, its capitalization, when organized, the location of the plants, the location of the main office, the names of the company's officers, the name of the purchasing agent and sales manager, plant equipment, products manufactured and types of primary and secondary raw materials consumed.

In addition to the four sections mentioned above, the Directory contains special lists of: manufacturers and distributors of pig iron, ores and alloys; fabricators of structural steel, bars, sheets, tanks, plates and boilers; airplane manufacturers; merchants who specialize in used structural steel products; smelters and refiners of new and old metals; storage battery manufacturers; solder manufacturers; sheet metal stamping works; galvanizers; die casting plants; secondary metal smelters; railroad purchasing agents; copper, lead and zinc brands; scrap iron and scrap metal dealers in the United States and Canada.

The Directory is a valuable reference for the steel and metal industries and is of special value to purchasing agents and sales managers.

The *Standard Metal Directory* is published by the Atlas Publishing Co., 425 W. 25th St., New York 1, and sells for $10 a copy.

HOW TO BUILD A FARM WAGON HITCH

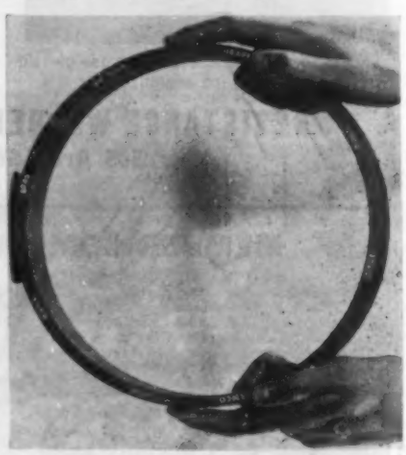


Courtesy The Lincoln Electric Co.

The farm wagon in the picture was built by cutting an old truck frame and welding it into a suitable size for a wagon trailer. The method of fabricating and welding the hitch to the farm wagon is shown in the sketch. The welds were made with $^{5}/_{32}$-in. rod.

WELDING DISSIMILAR METALS

Eight diversified metals are "welded" in the ring shown above, prepared by the research staff of the American Welding & Manufacturing Co., Warren, Ohio, to demonstrate the versatility of controlled-technique resistance welding.



Strength is not sacrificed in any of the weld areas, which join 1020, 1040 and 1060 steel, 52100 and 8745 alloys, 18-8CB stainless, Monel and Armco metal to form a continuous structure.

EUTECTIC "*Low Temp*" EUTECTRODES*
for faster, better, more economical METAL ARC WELDING

"*LowTemp*" EUTECTRODE 24 for CAST IRON *saved!*
FROM SCRAP—HEAVY IRON CASTING *without* PRE-HEATING, DIFFICULT MACHINING, PLANT SHUT-DOWN

This 400 lb. cast iron casting was put back into service in 3 hours by arc welding with "*LowTemp*" EUTECTRODE 24. A structurally strong, color matching, machinable weld was obtained *without preheating!* This was possible because of the amazing surface alloying action of this special flux-coated electrode. Use this revolutionary "*LowTemp*" EUTECTRODE 24 to salvage your large and small, broken or worn cast iron parts.

EUTECTIC "*LowTemp*" EUTECTRODES
are new types of metal arc welding electrodes which — 1. Weld at lower base metal temperatures. 2. Deposit welds at exceptional high rates of speed. 3. Form welds equal to or better than base metal.

OTHER OUTSTANDING "*LowTemp*" EUTECTRODES
STAINLESS "*LowTemp*" EUTECTRODES for stainless steels
"*LowTemp*" EUTECTRODE 28 for Brasses, Bronzes, etc.
"*LowTemp*" EUTECTRODE 2100 for ALUMINUM
"*LowTemp*" EUTECHROMS for HARD OVERLAYS
"*LowTemp*" EUTECTRODE 30 for COPPER

SOLVE YOUR METAL ARC WELDING PROBLEMS WITH EUTECTIC "*LowTemp*" EUTECTRODES*
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DESIGNATOR OF *Low Temperature* WELDING ELECTRODES
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VISIT OUR BOOTHS G-103 and A-180 at National Metal Congress, Atlantic City, Nov. 18-22.

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61

NEW PRODUCTS

The Society assumes no responsibility for the validity of claims in this Section

COPPER TUNGSTEN ALLOYS

A new line of copper tungsten alloys, available in the form of rods, bars and inserts, is now offered by Ampco Metal, Inc., Milwaukee 4, Wis.

These are produced to enlarge its line of Ampcoloy resistance welding electrodes and to provide a suitable alloy for special conditions where the electrodes are held over a fairly long period at high heat and pressures or where water cooling is not always available or adequate.

The main applications of these alloys are for projection and flash welding, die facing and inserts, electrical upsetting and forging dies and similar applications.

Standard resistance welding electrodes may be secured with copper tungsten facing or on special spot welding tips, or flash and projection welding dies with copper tungsten inserts.

The new alloy meets R.W.M.A. specifications and is available in a number of classes.

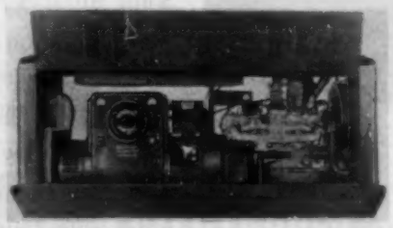
In addition to the above two silver tungsten alloys are being produced by Ampco in the form of rods, bars and inserts. These are suitable for applications such as circuit breaker contact material and arcing tips, and for circuit breaker facing material and special welding applications.

Additional information may be obtained from Ampco field engineers or by writing directly to the main office at Milwaukee.

COMBINATION GAS-ELECTRIC DRIVE 300-AMP. ARC WELDER

This compact combination drive Hobart welding machine consists of the standard 300-amp. generator and 20-hp. induction motor mounted on a heavy solid shaft coupled to a Chrysler 6-cylinder Industrial Engine through an over-running clutch coupling. This coupling allows the gasoline engine to drive the welding generator positively. However, should the gasoline engine be stopped and the generator be driven by the electric induction motor, the clutch will over-run, or free wheel. This action is entirely automatic—no levers or pins are required to be moved.

The induction motor is wound for dual voltage 220/440. This change-over is accomplished by throwing a double-throw knife switch either to the 220-v. position or the 440-v. position. The motor is started by means of a pushbutton across-line contactor which is designed to work in conjunction with the voltage change-over knife switch so that no changes are necessary in the contactor for 220- to 440-v. operation.



Combination Gas-Electric Drive 300-Amp. Arc Welder

The gasoline engine is furnished with an idling device, and all other features that are carried by the standard Hobart 300-amp. gas drive. In fact the unit carries all the features of the standard Hobart 300-amp. electric-driven machine as well as the gas drive, plus the over-running clutch coupling, and the 220/440-v. change-over switch.

This single-unit construction assures perfect alignment at all times, which will result in trouble-free operation. The clutch is practically wear-free, being of ball bearing construction with hardened races and sprags.

Great popularity is shown for this unit for specialized applications. The contractor or job welding shop operator with such a unit is able to take advantage of the cheapest power available. Should 220 or 440 v. three-phase be available, he is immediately ready to take advantage of it. If no electric power is available at the job site, the gasoline engine is there to fall back on.

This welder is also ideal for locations where power may fail. In this event, should the electric power fail because of line failure, or overload during the peak load operating point of the day, it is possible to start up the gasoline engine and carry on with the welding work.

This unit on a portable mounting can be very valuable to large chemical, oil, steel, etc., and other industries who have equipment spread over large areas and where power conditions vary over this area. When operating close to electric power source it can be taken advantage of, however, many of the applications will be in parts where power is not available, and in this case, the gasoline engine can be used.

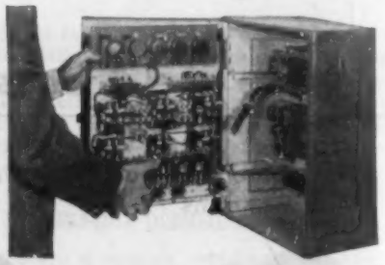
THE VAPORSPHERE

The Chicago Bridge & Iron Co., Chicago, Ill., announces the publication of a new 20-page booklet, "The Vaporsphere." It describes the method of reducing evaporation losses from flat-bottom tanks storing volatile liquids by installing a vapor-saving system with facilities for the temporary storage of vapor.

The method for determining the correct size of the Vaporsphere, which is used for the temporary storage of the vapor, is discussed together with the method of designing the vapor lines which connect the flat-bottom tanks to the Vaporsphere. The vapor pressure, expansion of air-vapor mixture and the flow of vapor in the lines can be read directly from charts included in the booklet.

SEQUENCE AND SEQUENCE-WELD TIMERS FOR RESISTANCE WELDING

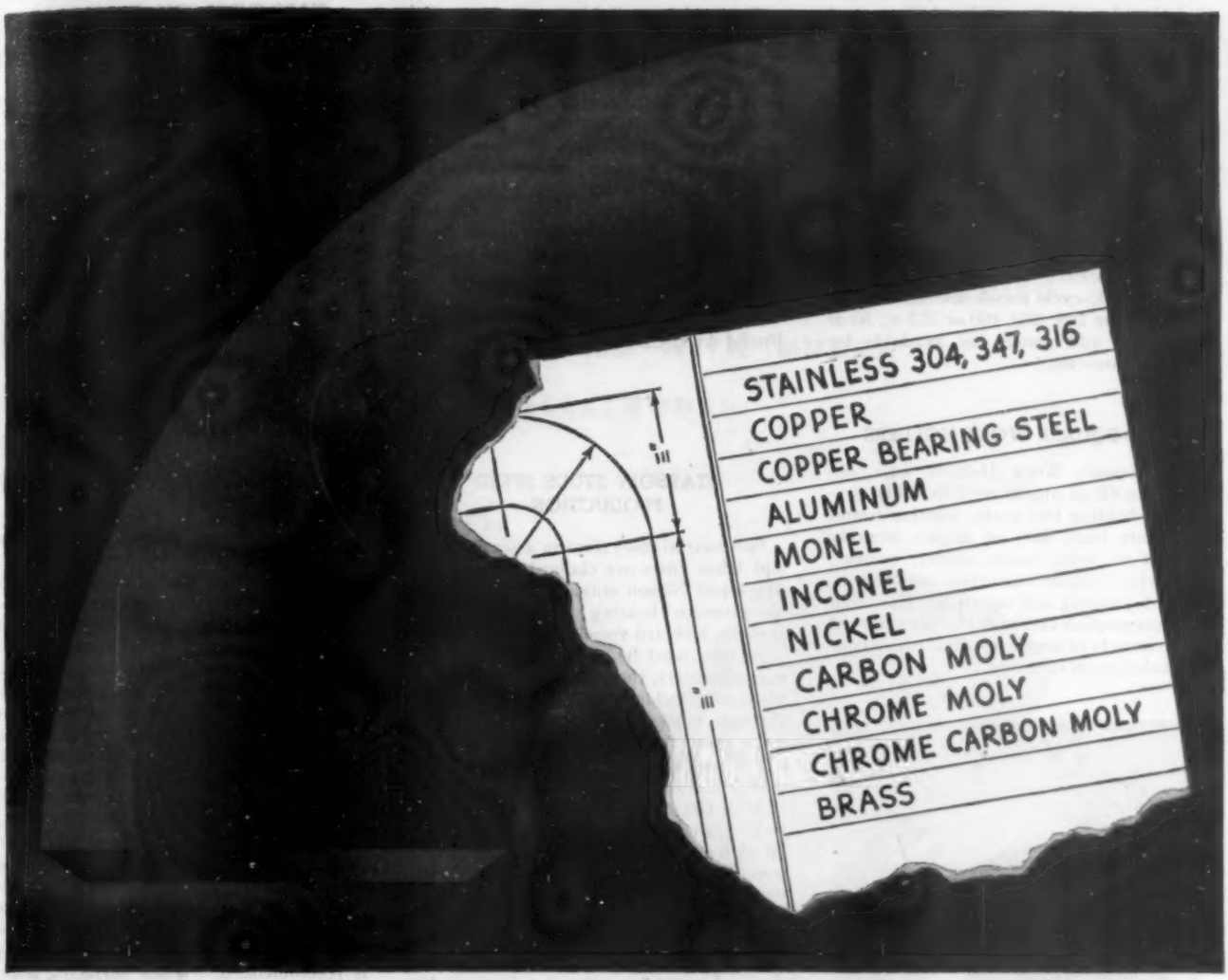
The Control Div. of General Electric Co. has announced the redesign of its complete line of sequence and sequence-weld timers for resistance welding. The new design permits quick change of the welding sequence, easy inspection and maintenance, and remote operation. It includes an improved electronic timing circuit which makes possible the consistent welding speed essential to high-production welding with short timing intervals.



The sequence timer is designed for applications requiring the highest degree of weld consistency. It coordinates the mechanical operation of an air- or fluid-operated spot or projection welder with the flow of welding current, as determined by a synchronous-precision weld timer. For less exacting applications, the sequence-weld timer provides the necessary control of both mechanical sequence of operation and nonsynchronous control of weld time. Both can be used with all standard control combinations in which ignitron contactors or synchronous-precision timers are used.

All electrical connections between the front and rear panels are made by plug connectors so that the front panel, or timing control section, can be removed in less than a minute and placed in another machine. This permits quickly replacing any one of a number of similar timing control sections with a single spare unit. In addition, timing control sections of different types can be interchanged without rewiring.

Features which simplify routine inspection and servicing include a completely



Which Alloy?

TUBE-TURN quality-controlled Welding Fittings and Flanges are available in a wide range of metals and sizes to meet virtually every piping need. Practical production and application experience has dictated the engineered development of every fitting design. The selection of each alloy was made only after careful research and close cooperation with alert piping engineers all over the country whose daily problem is to cope with specific conditions of heat, pressure, flow and corrosive attack.

Not just another fitting . . . but one which meets, in every way, the rigid requirements of planned, long-lived systems . . . systems in which every component part plays an important role.

Tube-Turn engineers are ready to work with you and give you the benefit of their wide background of experience in the use and production of welding fittings in all these alloys. For piping permanence in alloy systems, be sure the Welding Fittings and Flanges are trade-marked Tube-Turn.

TUBE TURNS (Inc.) Louisville 1, Kentucky. District Offices: New York, Washington, D. C., Philadelphia, Pittsburgh, Cleveland, Detroit, Chicago, Houston San Francisco, Los Angeles.

TUBE-TURN TRADE MARK **tt** *Welding Fittings and Flanges*

PIPING PERMANENCE SINCE 1927

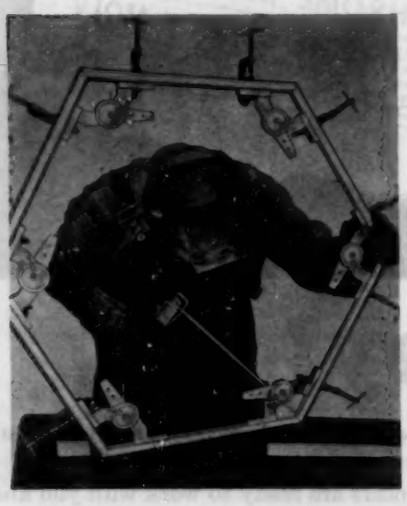
PETROLEUM | CHEMICAL | GENERAL PIPING | SHIPBUILDING | POWER | EQUIPMENT

redesigned wiring system in which most of the small resistors and capacitors are mounted on a terminal board; use of standard industrial-type relays which are familiar to electricians; and a hinged front panel which cuts inspection time. For the convenience of the operator, the timing control station can be mounted on the welding machine or elsewhere, as it is easily detached from the front panel.

The initiating circuit, normally 115 v., can be easily changed to 24 v., and a two-stage foot switch can be added at any time. All 60-cycle panels are suitable for operation on 208, 230, 460 or 575 v., 50 or 60 cycles, and panels are available for other frequencies.

DUO-SQUARE WORK HOLDERS

Duo-Square Work Holders were designed to fill an urgent need in industry—that of holding two parts, whether round or square bars, flats or angles, securely enough to weld, braze, solder, cement, glue, etc., without distortion and the inevitable tapping and squaring. How well they accomplish this task has been proved in thousands of applications in every conceivable type of industry.



Duo-Square Work Holders are cast aluminum alloy brackets supporting two clamping faces that are either positioned at fixed angles or adjustable to any angle, depending upon the model. They are in effect double vises that provide positive gripping where a vise cannot be used. Duo-Squares even in the larger heavy-duty models, are easily portable, simple to operate and their positive action permits accurate joining of parts in places impossible to reach with any other holding device.

The models available consist of the Adjustable, in which the two clamping faces are movable through 0 to 180°, the fixed Ninety, which makes possible accurate 90° joints, the fixed Straight, which permits straight-line butt joints and the 3-Way models, that provide an accurate means for making T-joints or corner-and-leg joints in one fast setup.

The 3-Way Series are now in the last stages preparatory to production. All other models, the Adjustable, the Ninetys and the Straights are available for immediate delivery.

McFerron-Myers Products Co., 308 Euclid Ave., Cleveland 14, Ohio.

STAYBOLT STUDS SPEED PRODUCTION

Substantial reductions in assembly time and labor costs are claimed for recently developed Nelson staybolt studs used on low-pressure heating boilers and low-pressure jacketed vessels.

As now used by several heating boiler manufacturers, the Nelson studs are automatically welded to the inner plates through holes drilled or punched in the outer shell. Welding is accomplished with the Nelson stud welding "gun," operating from a d.-c. welding generator.

After the staybolt stud is automatically welded, the projecting stud end is broken off with a light hammer blow at the groove provided, leaving the stud end flush with the outer plate surface. A flat washer is then dropped over the stud end, and is positioned in line with the inner surface of the plate by the shoulder provided on the stud. The washer acts as a back-up for the plug welding operation which completes the staybolt installation.

Because the staybolt studs are installed with the outer shell or casing in place, and are welded through the attachment holes, no problems of fit-up are encountered. Stud welds can be completed at the rate of 100 to 200 per hour with the fully portable Nelson gun. An automatic timer controls the weld cycle; the operator merely loads the staybolt stud and protecting ferrule into the gun chuck, inserts the chuck into the hole until contact is made with the inner plate, and pulls the trigger. Plug welding to complete the job is fast and easy because fit-up is perfect and weld metal is retained in correct location by the back-up washer.

Full information on Nelson staybolt studs and their proper applications may be obtained by writing to Nelson Sales Corp., 28th St. at Toledo Ave., Lorain, Ohio.

HARD-SURFACING ELECTRODE

Amsco *Resistwear*, the hard-surfacing rod recently developed by American Manganese Steel Division is a low-cost, high-carbon, chrome, molybdenum, shielded-arc electrode that can be deposited on any ferrous base metals. It will produce, as deposited, hardness of approximately 400 to 500 Brinell, depending upon the degree of dilution from the base metal.

This most recent addition to the Amsco line of Conservation Welding products is ideal for a wide range of applications where it is desirable to protect ferrous parts, subjected to severe abrasion with or without impact, with an overlay of a more wear-resistant material. *Resistwear* is an excellent substitute for manganese steel parts on abrasion applications where there is not sufficient impact to develop the full work-hardening properties for which austenitic manganese steel is well known.

Resistwear is available in coated form only for a.-c. and d.-c. application in 1/8, 5/32, 3/16 and 1/4 in. diameters by 14 in. long. Before application the base metal should be prepared to receive the hard-surfacing material by removing with a grinder and wire brush all rust, scale and the like. For best results straight polarity is recommended. When surfacing manganese steel, maximum hardness is obtained by two or more pass deposits.

Bulletin W-20-B on *Resistwear* will be mailed upon request. American Manganese Steel Div. of American Brake Shoe Co., Chicago Heights, Ill.).

SKETCH PAD

Jiffy Sketch is the name of a scale drawing pad that is being introduced by Jiffy Sales Co., Cleveland. It enables one to make properly proportioned drawings without use of ruler, drafting board or T-square, and it may be used in the shop or in the field as easily as in the office.

The Jiffy Sketch pad contains 75 sheets of high quality tracing tissue, enclosed within a cover jacket that consists of four cardboard flaps. Various scales are printed on three of the flaps. To use the pad, you simply fold back the cover flap

Dissimilar METALS GET HAPPILY MARRIED WHEN JOINED WITH MUREX ALUMINUM BRONZE ELECTRODES

Brass can be welded to steel...iron can be welded to copper...and many other combinations of commonly used metals can be joined together with high strength and excellent bearing qualities—when the welding is done with Murex Aluminum Bronze Electrodes.

The Murex line includes *five* aluminum bronze electrodes, each with outstanding welding characteristics and exceptional physical properties...each designed to provide a certain Brinell hardness of deposit...and *all five* are made to satisfactorily take care of *any* application that an experienced welder may find in a day's work.

The superior results provided by Murex Aluminum Bronze Electrodes are achieved with a minimum of penetration and with quick cooling. Write today for further information about these products and ask for your time-saving application chart.

METAL & THERMIT CORPORATION

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and then place one of the tissue sheets over the scale you wish to employ. Your drawing is made accurately to scale with the aid of the printed lines which show through the tissue.

According to the manufacturer, this pad has been endorsed by draftsmen, designers, engineers, surveyors, builders, field men, sales engineers, students, estimators, patent attorneys and architects. It is said to be a real time-saver for busy men who wish to convey their ideas quickly and accurately.

In many respects the Jiffy Sketch pad is superior to graph paper. Drawings made on this pad may be blue-printed. There are no ruled lines on the tissue to confuse the drawing. It gives all the advantages of ruled paper, with none of the disadvantages.

The pad measures approximately 9 x 12 in. Sheets are perforated for easy removal. Valuable information is printed on the back of each cover flap—basic mechanical drafting standards; electrical welding and architectural symbols; decimals of a foot; decimal equivalents of fractions, with circumferences and areas of circles.

Jiffy Sketch will be on sale at most dealers. The price is $1.65 each, or $1.50 each in lots of six or more. Or you may obtain one of the pads by sending a dollar to Jiffy Sales Co., 1878 E. 37th St., Cleveland 14, Ohio.

WELDING GOGGLE

A new head-rest welding goggle which can be instantly thrown into "off guard" position for rapid inspection of setups is announced by American Optical Co., Southbridge, Mass.

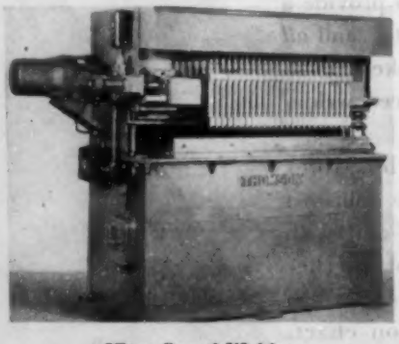
Developed to eliminate waste motion and speed up welding operations, the goggle is attached by a friction joint to a confortable head gear assembly. Using only one hand, the welder can flip the goggle above his eyes, where it is held securely by the friction joint, so that he has complete, unimpeded vision.

Adjustable for individual features, the goggle is equipped with opaque eyecups specially designed for wearing directly over eyes or over personal prescription glasses. It also has indirect, ventilated side shields which keep out stray light rays, sparks and metal splashes, yet provide ventilation to reduce fogging.

The goggle is available with either Noviweld or Noviweld-Didymium lenses in certain shades.

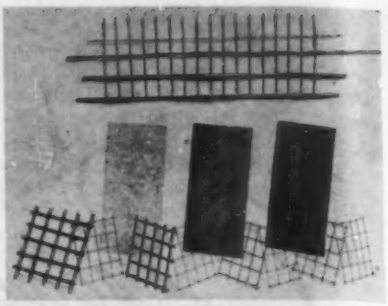
"ULTRA SPEED" WELDER FABRICATES WIRE MESH

Designed primarily for welding wire mesh such as is used for grilles, racks, trays, etc., this new Thomson Ultra Speed Spot Welder has many interesting possibilities for mass producing jobs involving large numbers of similar welds closely spaced on a uniform surface. The model shown has 25 electrodes arranged to weld up to 25 longitudinal wires spaced as desired across a maximum width of 48 in. The normal capacity ranges from 14 to 14 gage minimum to 0 to 0 maximum. Longitudinal wires can be fed into and through the machine continuously if desired. Spot spacing can be varied from a minimum of $1^1/_2$-in. between welds up. Wide spacing which requires fewer electrodes for the maximum work width accommodated by the machine is accomplished without removing electrodes by means of individual cut-out valves. To handle welds in which succeeding lines are made in a pattern such as diamond mesh or diagonal weave, a shuttle bar operated by a hydraulic cylinder moves the entire bank of electrodes right or left of the initial position.



Ultra Speed Welder

Two 50-kva. transformers with individual heat regulators and Weld-O-Trol Controls provide welding current, current being applied in rapid succession to pairs of electrodes as the carriage of the Ultra Speed Unit moves across the machine. Welding pressure is applied by a motor-driven hydraulic pump. Pressure is applied simultaneously to all electrodes and maintained during the complete cycle. Both pressure and current dwell are individually adjustable for any electrode so that mesh involving several different gages of wire can be fabricated.



Samples of Wire Mesh and Sheet Metal Work Produced by the Thomson Ultra Speed Spot Welder

Operation of the machine is both rapid and automatic. Tripping a floor switch starts the cycle with all electrodes (except any previously cut out) contacting the work. The two sections of the carriage driven by a worm and reversing motor move across the machine, each section of the carriage firing half the electrodes in rapid succession. A solenoid brake automatically stops rotation of the driving motor at the limit of travel and electrode pressure is released. The next contact of the floor switch repeats this sequence for the second series of spots with the carriage moving in the opposite direction. Further information may be obtained from Thomson Electric Welder Co., Lynn, Mass.

WELDING AQUEDUCT

Electric arc welding on a high-head steel section of the 41-mile Salt Lake Aqueduct line to be laid under the Provo River. The members are being held together for welding by a push-and-pull unit of ten tons capacity which is widely used for such applications—the Simplex Util-A-Tool, manufactured by Templeton, Kenly & Co., Chicago 44, Ill.

WHAT'S NEW?

Metalworking methods are constantly changing—new techniques, new materials, new equipment. You can keep in step with these new developments through membership in the A. W. S.

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Here's what you get for $15

(*Associate Membership $10*)

1. Monthly Section meetings where you can discuss your problems with specialists.
2. Codes, Specifications, and Standards made available in The Welding Journal at no extra cost to members.
3. Opportunity to work on new ideas with the Welding Research Council.
4. Subscription to The Welding Journal—your news-authority on welding.
5. Journal Supplement for all the news on research in progress.
6. Welding Handbook—the welding "Bible"—at no extra cost to members (reduced price to Associate Members).
7. Lecture courses through Welding Society Section groups.
8. Free Welding Yearbook to tell you Who's Who.
9. Annual Exposition.
10. Membership Certificate.

If you want to know more, call or write for a copy of "Progressing in Welding," a little booklet that describes in detail the activities of the society.

The AMERICAN WELDING SOCIETY

33 WEST THIRTY-NINTH STREET

NEW YORK 18, N. Y.

SECTION ACTIVITIES

BOSTON

The Boston Section held its first meeting of the season on October 7th at the Engineers' Club, Boston, and heard two interesting speakers.

E. E. Stoeckly of the Aircraft Gas Turbine Division of the General Electric Co., Lynn, was the dinner speaker and told of some of his experiences during a trip through France and Germany in 1945. He also discussed technical progress in Germany on Aircraft Gas Turbines. Lantern slides were used to illustrate his talk.

The technical speaker of the evening was E. J. Charlton, Manager of Development Engineering Lukens Steel Co. Mr. Charlton discussed Weldment Failures, describing the extent and probable causes of failures in weldments, and the various types of failures encountered. He gave case histories of some of these and indicated the methods by which such difficulties can be circumvented or corrected. Lantern slides were also used to illustrate his talk.

CINCINNATI

One hundred sixty-six members and guests attended dinner at the Manchester Hotel, Middletown, on September 24th. Charles R. Hook, President of the American Rolling Mill Co., presented an interested subject, "Travels Through South America."

After dinner there was a plant inspection of the East Side Works of the American Rolling Mill Co.

CLEVELAND

Robert C. Hienton, Director of Industrial Development for the Cleveland Electric Illuminating Co., spoke on "Industrial Development in the Cleveland Northeast Ohio Area," at the first meeting of the year on October 9th at the Cleveland Engineering Society.

Mr. Hienton is spearheading the Cleveland Electric Illuminating Co.'s campaign to "sell" Cleveland to industries everywhere as the best location in the nation for manufacturing, distribution and management headquarters. He is Vice-Chairman of the Ohio Industrial Development Committee of the Ohio Chamber of Commerce.

"Some Aspects of the Atomic Bomb Project" was the subject of a dinner talk by former Col. John Lansdale, Jr., who has now returned to active legal practice with Squires, Sanders & Dempsey.

Col. Lansdale entered the Army as 1st Lieutenant in 1941 and his primary responsibility during the war was to make certain that the atom bomb remained a secret. He was actually in charge of intelligence and security pertaining to the Manhattan Project with which everyone is now so familiar. While much of the security work must necessarily remain secret, Col. Lansdale discussed some phases of the project which had not previously been publicized.

DAYTON

Frank E. Kessler, Field Engineer of the Welding Equipment and Supply Co., Detroit, Mich., was the guest speaker for the first meeting of the year held on September 25th. Mr. Kessler's subject, "Tool and Die Welding," was one of the topics chosen for discussion by the Section in a recent poll of members. Two slide films were shown—"Let's Get the Lowdown," and "Let's Do It Right." A question and answer period followed.

A plant visitation was made to the Hobart Bros. Co., Troy, Ohio, on October 23rd.

DETROIT

About 350 members and guests met at Progressive Welder Co. to enjoy the excellent program prepared by F. Johnson and John D. Gordon. The photograph shows Julius R. Brueckner, John D. Gordon and Fred Johnson, taken at the first meeting of the season held on September 13th, Friday.

J. R. Brueckner J. D. Gordon F. Johnson

HARTFORD

Dinner meeting was held on Thursday, September 19th, at The City Club, Hartford. Following dinner, Ira T. Hook of The American Brass Co., spoke on the subject "Properties of Copper Alloys and Their Effects on Welding Operations."

Following Mr. Hook's talk, the American Brass Co.'s film on the actual mining and production of copper in Chile was shown, as well as another film entirely unrelated—"How Not to Conduct a Meeting," by Colonel Stoopnagle.

INLAND EMPIRE

The third regular meeting was held on Tuesday, August 27th, at the Spokane Hotel. Chairman Thomas Sholes, Gibson Welding Supplies, opened the business meeting following a dinner which was attended by 26 members and guests.

Messrs. Halliday, Miles and Lavelle of the Allied Weldery, Coeur D'Alene, Idaho, presented a technical skit on "What to Do When Trouble Comes."

Underwater Cutting, its adaptation and uses, was the topic of the September meeting. William Miller of the United States Bureau of Reclamation, Coulee Dam, Washington, was the guest speaker. A film on the above subject was also shown.

KANSAS CITY

Bella Ronay of the U. S. Naval Eng. Experiment Station, Annapolis, Md. was the speaker at the meeting held on September 9th at the Hotel Continental. Dinner preceded the meeting.

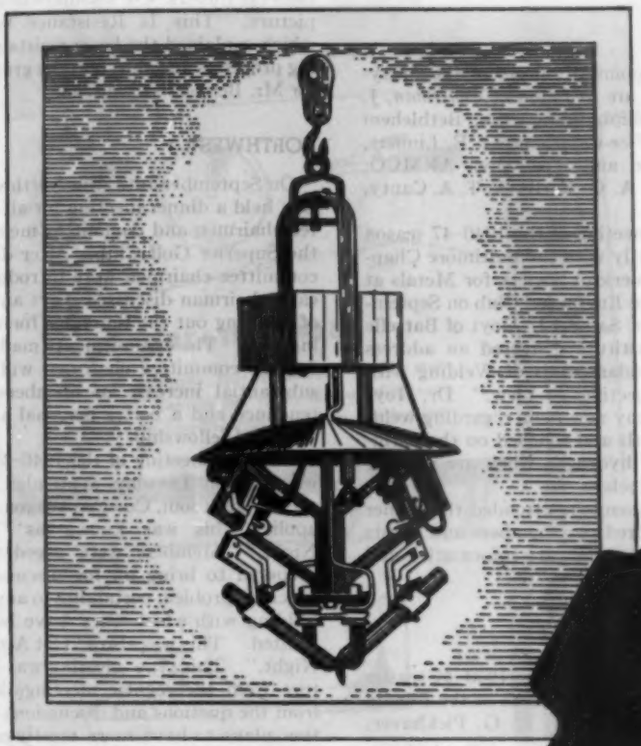
LEHIGH VALLEY

The Lehigh Valley Section held its first meeting of the 1946–47 season on October 7th, at the Hotel Bethlehem.

The main session was preceded by a dinner, at which time the Chairman, Gilbert E. Doan, introduced the guest of the evening, Dr. Comfort A. Adams, the founder and first President of the Society. Dr. Adams gave an informal talk on "Fundamental Research."

The dinner was followed by a technical meeting. Dr. Adams introduced the speaker of the evening, Dr. Robert D. Stout of Lehigh University, who spoke on

LIKE TO TRY WELDING WITH THIS?



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The Zerener "blow pipe"

Arc, drawn between two carbon electrodes arranged to form a V, is forced toward work by electro-magnet. Invented in 1898 by Dr. Zerener of Berlin. It is called "blow pipe" because of the impinging arc. It was too complicated for practical use.

WELDING with this relic of the 'nineties would be an interesting stunt, but you'd lose your shirt if you'd put it to work regularly on the jobs in your plant.

Only with modern methods and equipment can there be profitable production. So, wherever you employ electric arc welding, use RACO Heavily Coated Electrodes. RACO rods embody the experience of 27 years' specialization and the latest *proved* advancements in electric arc welding electrodes.

Name your toughest welding job. We will be glad to send you samples of RACO Electrodes so you can see for yourself that the job can be done better and at lower cost with a RACO product. Write . . .

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SINCE 1919 PRODUCERS OF ARC WELDING ELECTRODES AND WELDING RODS

"The Lehigh Restraint Specimen." Dr. Stout discussed a method of varying quantitatively the restraint against which a weld shrinks upon cooling, and the practical applications to which the method can be applied.

The speaker's remarks were followed by a floor discussion with the members participating.

LONG BEACH

An organization meeting was held of the newly formed Long Beach Section on August 30th in the High School Auditorium, Long Beach. The officers and chairmen of committees elected are as follows: *Chairman*, V. M. Goode, Long Beach; *Vice-Chairman*, A. R. Wynn, Long Beach; *Secy.-Treas.*, Geo. Duncan, San Pedro Calif.; *Chairman Technical and Codes*, Edward Dash, Long Beach; *Chairman Membership Committee*, Jack Yong, Long Beach; *Chairman Entertainment*, C. L. Brudi, Long Beach.

The first regular meeting of the Section was held on September 20th at the John Dewey High School. Dinner at Allen's Shore Dinners preceded the meeting. Dinner speaker was Captain Murphy, Production Officer, U.S.N. Shipyard, who spoke on "My Experience in Welding and the Importance of Design for Welding."

John Ross of Handy and Harman was the speaker at the technical meeting. His subject was "New Developments in Low Temperature Brazing." Slides were used to illustrate this very satisfactory address.

LOUISVILLE

The September meeting of the Louisville Section was held in the Ship Room of the Kentucky Hotel, Tuesday, September 24th.

A. F. Chouinard of the National Cylinder Gas Co., gave an illustrated talk on "Flame Shape Cutting Processes." This talk and slides showed various types of cutting machines, and illustrated the versatility and adaptability of the latest equipment to peacetime products.

Quite a general discussion on the need for stress relieving on various weldments and welded products that have been flame cut and welded.

MAHONING VALLEY

Officers and members of committees for the coming year are as follows: *Chairman*, Arthur L. Williams, The Federal Machine and Welder Co.; *Vice-Chairman*, Wilson Scott, Westinghouse Electric Corp.; *Secy.-Treas.*, H. R. Strohecker, The Youngstown Welding & Eng. Co.; *Asst. Secy.*, L. M. Klentz, The Taylor-Winfield Corp.; *Membership Committee*, Robert Fisher, Chairman, W. M. Tam, Robert Haas, F. Z. Hippler; *Program Committee*, Wilson Scott, Chairman, Arthur W. Waldo, C. R. Riggle, Harry Cook; *Publicity Committee*, A. B. Alexander, Chairman, J. Carroll Jennings, H. Ross Strohecker.

The October meeting of this Section was held on the 9th in the Ohio Edison Auditorium, Youngstown. Dean Louis A. Deesz, School of Engineering, Youngstown College, spoke on "Atomic Energy." Dean Deesz is one of very few persons qualified to speak on the subject of atomic energy. He is one of the speakers approved by the National Committee on Atomic Information. Because of his practical background in engineering he presented a highly interesting address on the applications of this important new development.

MARYLAND

Newly appointed officers of the Maryland Section are as follows: *Chairman*, J. W. Gore, Shipbuilding Div., Bethlehem Steel Co.; *Vice-Chairman*, G. E. Linnert, Rustless Iron and Steel Div., ARMCO; *Secy.-Treas.*, A. C. Earlbeck, T. A. Canty, Inc.

The first meeting of the 1946–47 season was held jointly with the Baltimore Chapter of the American Society for Metals at the Baltimore Engineers' Club on September 16th. Dr. Samuel L. Hoyt of Battelle Memorial Institute delivered an address entitled "Fundamentals of Welding with Practical Objectives in View." Dr. Hoyt presented many new facts regarding weldability of steels and touched on the harmful effects of hydrogen when arc welding hardenable steels.

Fifty-two members attended the dinner and one hundred two members and guests were present at this very informative and interesting meeting.

MICHIANA

The first meeting of the 1946–47 season was held on September 19th at the Bendix Legion Post No. 284. L. G. Pickhaver, Welding Engineer with the General Electric Co., spoke on "Three Methods of Gaseous Shielded Arc Welding—Atomic Hydrogen, Argon and Helium." The talk was preceded by a showing of the General Electric film "The Inside of Atomic Hydrogen Arc Welding." Approximately 35 members and guests were present.

The following have been elected officers of this Section for the 1946–47 season: *Chairman*, Gladstone C. Hill; *Vice-Chairman*, John A. Grodrian; *Secy.-Treas.*, W. G. Fassnacht; *Directors (2 years)*, William A. Gage, Donald Kyler.

MILWAUKEE

Regular monthly meeting of the Milwaukee Section was held on Friday, September 27th. After-dinner speaker was Frank McGuire, Division Eng., The Linde Air Products Co., Chicago. Mr. McGuire spoke on the extraordinary subject of "Synthetic Rubies and Sapphires."

The main speaker was P. J. Patton, Regional Manager, Ransome Machinery Co., Chicago. "History and Development of Welding Positioners and Turning Rolls" was Mr. Patton's topic. Mr. Patton pointed out the savings that can be maintained by means of welding positioners and turning rolls for increasing welding speeds, etc.

NEW YORK

The September meeting held on the 11th featured Resistance Welding. L. M. Benkert of the Progressive Welder Co., Detroit, spoke on "New Applications of Resistance Welding." Mr. Benkert traced the development of resistance welding machines, particularly as they applied to the automotive industry. Mr. Benkert also discussed the recently developed storage battery welding machines.

The talk was preceded by the showing of General Electric Co.'s sound-color motion picture, "This Is Resistance Welding," which explained the basic resistance welding processes and thus laid the groundwork for Mr. Benkert's discussion.

NORTHWEST

On September 10th, the Northwest Section held a dinner meeting for all committee chairmen and committee members, at the Superior Golf Club. After dinner all committee chairmen were introduced and each chairman discussed ways and means of carrying out the functions for the coming year. The commitments made by the various committee chairmen will show a substantial increase in membership, attendance and a better personal acquaintance and fellowship.

The first meeting of the 1946–47 season was held on Tuesday, September 24th, in the Lodge Room, Covered Wagon, Minneapolis. This was known as "Problem Night." Members were urged to come prepared to bring up for discussion any practical problem pertaining to any type of welding with which they have been confronted. This was also a "Get Acquainted Night." This type meeting was a departure from the regular meetings held and from the quetions and discussions the Section plans to have more meetings of this type throughout the year.

NORTHWESTERN PENNSYLVANIA

This Section opened the 1946–47 season with a meeting at the Sunset Inn, Tuesday, September 24th. Dinner preceded the meeting. G. O. Hoglund of the Aluminum Co. of America, spoke on "Welding and Brazing Aluminum Alloys" and showed movies of the processes used in welding aluminum. He also had samples illustrating the various joints, etc.

PASCAGOULA

Al Olsen, Welding Engineering of The Linde Air Products Co., presented an exceptionally well-received talk on "Automatic Welding" at the October meeting held at Lincoln Hall.

The next meeting will be held on Tuesday, November 12th, at the 12th Street Auditorium, at 6:30 P.M. Dinner meeting. Speaker will be L. M. Dalcher, Technical Secretary of the AMERICAN WELDING SOCIETY.

PEORIA

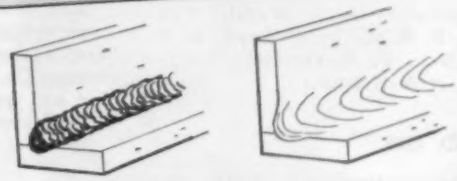
The first meeting of the season was held by the Peoria Section on Wednesday, September 18th, at the R. G. LeTourneau plant in Peoria. After a very well-conducted tour through the plant, observing fabrication and welding of their products, the group met in one of the cafeterias where lunch was served and a discussion period was held. There were 80 present

FOR HIGH SPEED, HIGH QUALITY WELDING

—USE DH-2

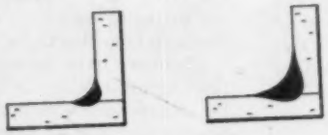
GREATER SPEED

DH-2 is a really fast electrode — for more pounds of deposit per hour, less welding cost. It's easy to handle with minimum spatter loss.



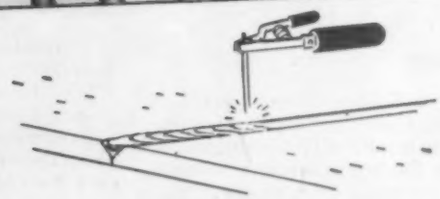
BETTER APPEARANCE

Weld metal "feathers out" — neat and uniform. It eliminates notched effect along weld edge — improves product appearance.



MEDIUM OR DEEP PENETRATION

If you desire medium penetration, you weld at normal amperages. You get deep penetration at high amperages.



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DH-2 is a "specialist" — designed specifically for horizontal, flat fillet and groove welding — proved the country over.

"SM"	"FR"	"CM-5O"	"FW"	"AC-3"	"PF"	"AC-1"	"AP"
AWS E-6013	AWS E-6012	AWS E-7011	AWS E-6020	AWS E-6013	AWS E-6012	AWS E-6011	AWS E-6010

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DH-2 is one of many types of P&H electrodes which meet every welding need. Above are just a few of the complete P&H mild steel group. Ask for complete line booklet R-7.

AMERICA'S MOST COMPLETE ARC WELDING SERVICE

DC WELDERS · AC WELDERS · WELDING ELECTRODES · WELDING POSITIONERS · WELDING PRODUCTION CONTROL SYSTEMS · ELECTRIC HOISTS

and, from comments received, the meeting was very beneficial to all.

PHILADELPHIA

Regular monthly meeting of the Philadelphia Section was held on September 16th at the Engineers Club. H. R. Isenburger of the St. John X-Ray Laboratory, Califon, N. J., presented an address on "The Value of Radiographic Inspection to the Welding Shop."

New Officers for the Section are as follows: *Chairman*, H. B. Seydel; *Vice-Chairman*, E. R. McClung; *Treas.*, W. F. Carson; *Secy.*, K. W. Ostrom; *Past Jr. Chairman*, A. A. Holzbaur.

PORTLAND, ORE.

September meeting of this Section was held on the 17th at the Mallory Hotel. At the dinner a motion picture entitled "Clean Water" was shown through the courtesy of the Portland General Electric Co. This was a very interesting picture on water polution.

Joe L. Morris, Engineer, was the speaker at the technical meeting. Mr. Morris spoke on "Peening Weld Deposit for Stress Relief," which was very well received.

PUGET SOUND

Joe L. Morris, Graduate Student in Welding Research, University of Washington, presented the results of his investigations of Peening at the September 25th meeting held in the Engineers Club, Seattle. Mr. Morris' paper was a résumé of his thesis for the Master of Science degree in Mechanical Engineering.

A film "New Horizons in Welding" was shown through the courtesy of the Harnischfeger Corp. This is a new sound picture.

ROCHESTER

The first meeting of the new season was held at the University of Rochester on October 3rd.

Harry V. Kough, Regional Manager, Eutectic Welding Alloys Corp., was the principal speaker. He explained the practical applications of eutectic welding and the progress made during the war in overcoming difficult or impossible joining of metals by other processes.

A number of slides were shown of products that had been fabricated by eutectic welding with Mr. Kough explaining the method and material used in each instance.

After the lecture the membership went to the shop where the speaker assisted Omar Nichols, Field Engineer, for the same company, in demonstrating the various ways of joining similar and dissimilar metals.

Mr. Kough's talk and demonstrations were well received by the 70 members and guests present. Films loaned by the Aluminum Co. of America showing the brazing and spot welding of aluminum were also presented.

SAN FRANCISCO

A High Frequency Heating Conference sponsored by a number of organizations, including the San Francisco Section of THE AMERICAN WELDING SOCIETY, was held on September 5th and 6th in the Auditorium of the P. G. and E. Building, San Francisco.

SOUTH TEXAS

September meeting of this Section was held on the 26th at the Houston Engineers' Club. Dr. D. C. Smith, Director of Research, Harnischfeger Corp., presented an interesting discussion on "Welding Electrode Coatings and Their Effect on Deposited Weld Metal."

SYRACUSE

Regular monthly meeting of the Syracuse Section was held on September 18th at the Hotel Syracuse. A motion picture, "To New Horizons," was shown. This is an imaginary conception of life in 1960 taken from the General Motors exhibit at the New York World's Fair.

The feature speaker was T. B. Jefferson, Editor of *The Welding Engineer*, whose subject was "Welding in the Post-War World." Highlights of Mr. Jefferson's talk were Welding vs. Riveting, the Consulting Engineer, Welding—A Tool or a Trade and Education for Welding.

WESTERN MICHIGAN

The Western Michigan Section announces the election of the following officers for the fiscal year: *Chairman*, Wm. H. Slaughter, Slaughter Mfg. Co.; *Vice-Chairman*, Everett Mattson, C. O. Porter Machine Co.; *Secy.-Treas.*, R. Dudley Layman, Layman Welding Supply Co.

YORK-CENTRAL PENNSYLVANIA

The first meeting of the new season was held on October 2nd in the Engineering Building, York, Pa.

"Your Section's Aims for the Present Season" was presented by Chairman Marvin G. Sedam of the Alloy Rods Co.

"Low-Alloy High-Strength Steels" was presented by L. M. Dukelow, Metallurgical Engineer, Jones and Laughlin Steel Corp.

A 15-min. discussion period followed.

CANADIAN

The first meeting of the 1946–47 series of the Hamilton Chapter of the Canadian Welding Society was held on Tuesday, October 8th, at McMaster University, Hamilton. This was a "Stump the Experts Night" with four experts—Messrs. R. M. Gooderham, Welding Consultant; H. Thomasson, Canadian Westinghouse Co. Ltd.; W. J. Stayura, Canadian Liquid Air Co. Ltd.; and F. E. Benson, Canadian Ramapo Iron Works Ltd.

Members have been invited to attend the Lecture Course series to be presented by the Ontario Chapter of the American Society for Metals, starting on Wednesday, October 9th, at 8 P.M. in the Westinghouse Auditorium, Hamilton, and continuing for eight consecutive Wednesdays, ending November 30th. The overall topic is "The Properties and Treatment of Iron and Steel."

The opening meeting of the season of the Toronto Chapter was held on October 1st at the Club Top Hat, Lake Shore Road. Dinner was at 6:45 P.M. Meeting at 8 P.M. A "Stump the Experts" session was held with the following experts—J. S. Fullerton, Handy & Harman; W. W. Brumby, English Electric Co.; R. M. Gooderham, Consulting Engineering; H. J. Nichols, Bureau of Mines; Gordon Anderson, Dominion Oxygen Co.; and Les Hazelwood, George Green Welding Co.

List of New Members

September 1 to September 30, 1946

BOSTON

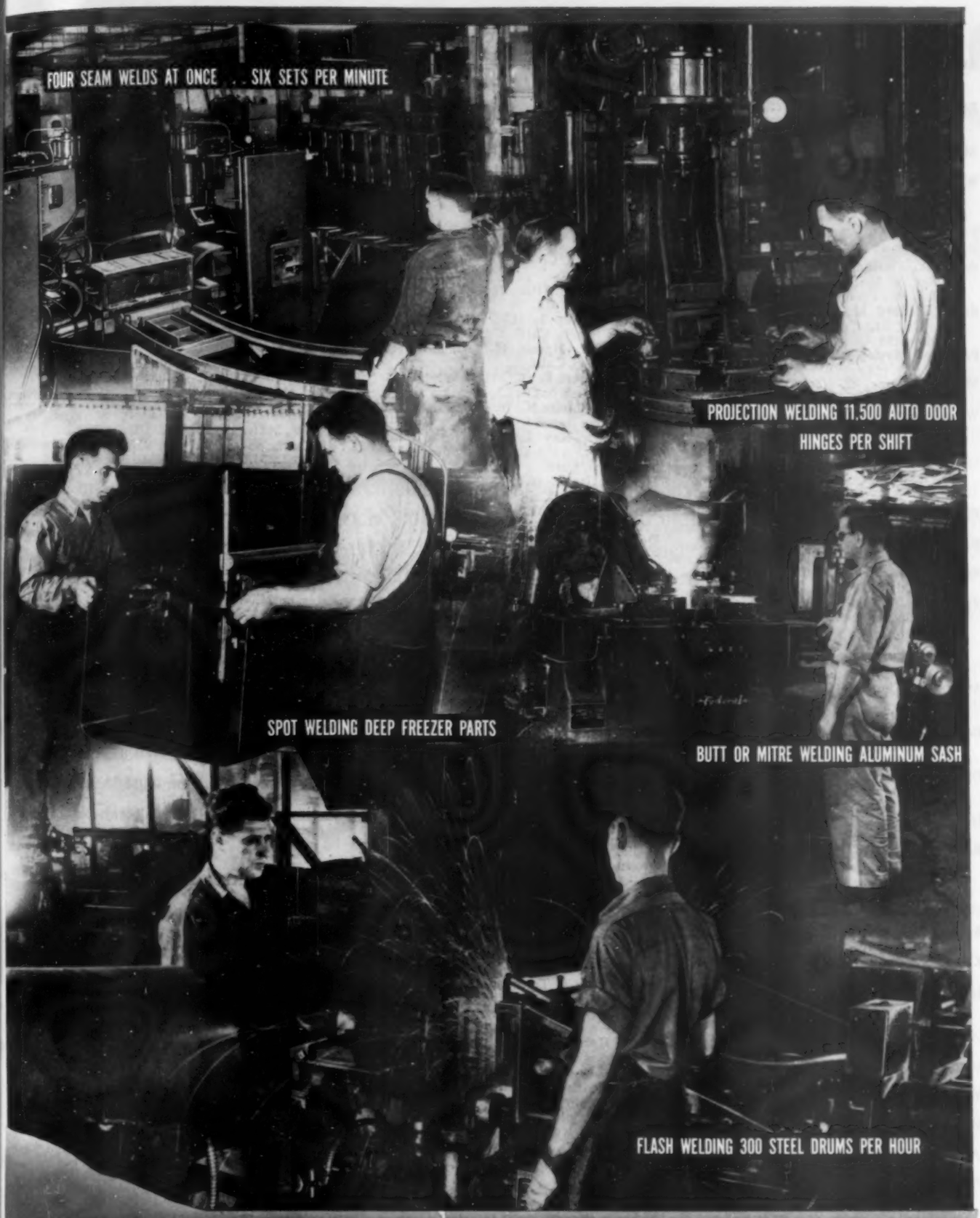
Picas, Andrew A., Jr. (C), 81 Linden Ave., Malden, Mass.

BRIDGEPORT

Johnston, William A. (B), 1350 Old Kings Highway, Fairfield, Conn.

CANADA

Nichols, H. J. (B), Physical Metallurgy Res. Lab., 568 Booth St., Ottawa, Ont., Canada.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Anderson, Glenn Eugene, Sr. (C), Chicago Welding Sales Co., 3349 W. Ogden Ave., Chicago 23, Ill.
Fesbusch, Charles P. (B), Gasflux Supply Co., 4442 N. Western Ave., Chicago 25, Ill.
Steele, Charles W. (B), 530 Washington Blvd., Oak Park, Ill.
Winchell, Robert L. (C), 307 Gordon Ave., Coal City, Ill.

CINCINNATI

Bostwick, William G. (B), Precision Welder & Machine Co., 138 E. McMicken St., Cincinnati 10, Ohio.
Boyd, Richard M. (C), Harris Calorific Sales Co., 342 Crescent Ave., Box 183, Lockland 15, Ohio.
Frommel, Marion B. (C), 314 Eight Ave., Dayton, Ky.
Martin, William G. (C), 3769 Aylesboro Ave., Cincinnati, Ohio.
Wiley, John (B), The Trailmobile Co., 31 St. & Robinson Ave., Oakley 9, Cincinnati, Ohio.

CLEVELAND

Blosser, Kermit D. (C), Ric-Wil Co., 53 Antles Ave., Barberton, Ohio.
Kyle, Robert A. (C), The Burger Iron Co., 1324 Firestone Pkwy., Akron 1, Ohio.
Smith, E. W. P. (C), 18106 Clifton Rd., Lakewood 7, Ohio.
Vickery, J. F. (B), General Elec. Co., 4966 Woodland Ave., Cleveland, Ohio.

DAYTON

Anderson, Thomas (C), Miami Welding Co., 1936 E. Monument St., Sta. A, Dayton, Ohio.
Corbet, Harold L. (C), The Graves & Marshall Co., 720 E. Monument Ave., Dayton, Ohio.
Dieterle, John (B), Miami Welding Co., 1936 E. Monument St., Sta. A, Dayton, Ohio.
Israel, David F. (C), 1939 E. First St., Dayton 3, Ohio.
Radford, Jack F. (B), Crosley Corporation, Richmond, Ind.

DETROIT

Bruen, Thomas E. (B), 16904 Braile Ave., Detroit 19, Mich.
Klees, Ralph A. (B), 19500 W. 8 Mile Rd., Detroit 19, Mich.
Lindstrom, Henry L. (B), c/o Westinghouse Elec. Corp., 5757 Trumbull, Detroit 31, Mich.
Linton, Jerry (B), 420 Cherry, Lansing, Mich.
Long, Thomas (C), 3893 Robina, Berkley, Mich.
McDougall, Bruce L. (B), 5731 Bewick, Detroit 13, Mich.
Mercier, Marcel E. (B), 2973 Garland Ave., Detroit 14, Mich.
Overture, Clarence A. (B), 2519 St. Clair River Dr., Algonac, Mich.
Pippel, Donald C. (B), 301 S. York, Dearborn, Mich.
Slaughter, William M. (C), R. C. Mahon Co., 6479 E. Eight Mile Rd., Van Dyke, Mich.
Smith, Frank S. (B), 15919 Ferguson Ave., Detroit 27, Mich.

HARTFORD

Firtion, Harold L. (C), c/o Geo. P. Clark Co., Windsor Locks, Conn.

KANSAS CITY

Crandell, Henry A. (B), 3625 Warwick Blvd., Kansas City, Mo.

LEHIGH VALLEY

Hartman, James B. (B), Dept. of Mechanical Engineering, Lehigh University, Bethlehem, Pa.

LONG BEACH

Allen, Glenn C. (C), 847–18th St., San Pedro, Calif.
Bowen, J. B. (B), 1684 E. 130th St., Compton, Calif.
Brudi, Carlton L. (C), 3365 Easy Ave., Long Beach, Calif.
Burkholder, Harold H. (B), Box 1405, San Pedro, Calif.
Butler, Albert F. (C), 1936 W. 19th St., Long Beach 6, Calif.
Conshafter, John N., Jr. (C), 2119 W. 19th St., Long Beach 6, Calif.
Davenport, Ray L. (C), H. I. Tullis, 353 W. Pacific Coach Highway, Long Beach 6, Calif.
Davison, Ira L. (B), 1050 Dawson Ave., Long Beach, Calif.
Davison, Lester O. (B), 238 W. 21st St., Long Beach 6, Calif.
Duncan, George (C), 1501 Branco Ct., San Pedro, Calif.
Ezell, Thais T. (C), 109 S. Mitchell, Long Beach, Calif.
Focquer, George W. (C), U. S. Naval Shipyard, Terminal Island, Calif.
Frazier, Robert F. (C), 1332 Chestnut Ave., Long Beach, Calif.
Goode, Vivian M. (C), 262 Covina Ave., Long Beach 3, Calif.
Hayden, Hoyt E. (C), 4747 Faculty Ave., Long Beach 8, Calif.
Hilse, Arthur R. (B), 368 E. 238th St., Wilmington, Calif.
Kennedy, Frank J. (C), R. F. D. 1, Box 355, Garden Grove, Calif.
Kuelper, Stephen L. (C), 3517 Gale, Long Beach, Calif.
Labs, David G. (C), 3212 San Francisco Ave., Long Beach 6, Calif.
Miller, Clay W. (B), 1207 E. Hill St., Long Beach 6, Calif.
Owens, Lee L. (C), 353 W. Pacific Coast Highway, Long Beach 16, Calif.
Peters, John (C), 2119 Traver Ct., San Pedro, Calif.
Petrucelle, John T. (C), 4253 S. Harvard Blvd., Los Angeles 37, Calif.
Platt, Roy M. (C), 333 W. 119th St., Long Beach 3, Calif.
Quillin, J. (C), Terminal Is. Navy Shipyards, San Pedro, Calif.
Regna, M. L. (C), 4901 Virginia Ave., N. Long Beach 5, Calif.
Ritko, Harold L. (C), 721 Cota Ave., Torrance, Calif.
Rogers, Alfred W. (C), 517 E. 46th St., Long Beach 5, Calif.
Schexschnider, Lee (B), 239 E. 6th St., Downey, Calif.
Senft, C. E. (C), 512 S. Chester Ave., Compton, Calif.
Simmons, Leo G. (C), 423 E. 19th, Long Beach 6, Calif.
Vezeau, Bernard J. (C), 3261 Golden Ave., Long Beach 6, Calif.
White, J. W. (C), 3206 Oregon St., Long Beach 6, Calif.
Williams, Ardis A. (B), 224—13th St., Seal Beach, Calif.
Wortham, Robert B. (C), 15313 Arcturus Ave., Gardena, Calif.
Yaun, Fred (C), 425 Daisy Ave., Long Beach 2, Calif.
Young, Jack M. (C), 1565 Judson Ave., Long Beach 6, Calif.

LOS ANGELES

Maxham, L. (C), 8141 Elizabeth Ave. South Gate, Calif.
Pence, Fred M. (B), 5119 District Blvd., Los Angeles 22, Calif.

MAHONING VALLEY

Williams, Arthur L. (B), 551 Kenmore Ave., N. E., Warren, Ohio.

MARYLAND

Byron, C. Gordon (B), 1532 Mt. Royal Ave., Baltimore 17, Md.
Metius, Richard E. (C), 2505 Yorkway, Apt. C, Dundalk 22, Md.

MILWAUKEE

McFarland, J. W. (C), 940 W. St. Paul Ave., Milwaukee 3, Wis.
Rinehart, William G. (C), 2151 S. Robinson St., Milwaukee 7, Wis.

NEW JERSEY

Birch, William (B), 332 Reserve St., Boonton, N. J.
Clark, Peter M. (B), 1005 Hudson Blvd., North Bergen, N. J.
Peterson, Clyde (C), 7 U. Prospect St., Caldwell, N. J.
Raduses, Stanley (B), 295 Ave. A, Bayonne, N. J.

NEW ORLEANS

Barnett, C. F. (C), P. O. Box 4, Denham Springs, La.
Henry, Sam G. (C), 345 Bedford Dr., Baton Rouge 12, La.
McKay, Albert F. (C), 2915 Jefferson Ave., Baton Rouge, La.
Virgets, N. M. (C), 1949 Mulberry, Baton Rouge, La.

NEW YORK

Borst, Wm. H. (C), 302 Manor Rd., Douglaston, N. Y.
Hamilton, Cecil G. (B), 220 Charles Ave., Staten Island 2, N. Y.
Heinz, Edward J. (B), 19 Cooper St., New York 34, N. Y.
Kelly, George (C), 468 E. 160th St., Bronx 56, N. Y.
Linsley, Horace E. (C), *The Iron Age*, 100 E. 42nd St., New York 17, N. Y.

NORTHERN NEW YORK

Childs, Wylie J. (C), Ricketts Lab., R. P. I., Troy, N. Y.

NORTHWEST

Dow, Lewis W. (C), 3313—38th Ave. S., Minneapolis 6, Minn.
Knudsen, Fred L. (C), 1769 Beech St., St. Paul 6, Minn.
Menk, G. A. (C), 23 S. 2nd St., Minneapolis 1, Minn.
Rosenwald, George F. (B), County Rd. B & Walnut St., St. Paul 8, Minn.
Wallner, L. D. (C), Lincoln Electric Co., 307 S. 1st Ave., E. Duluth, Minn.

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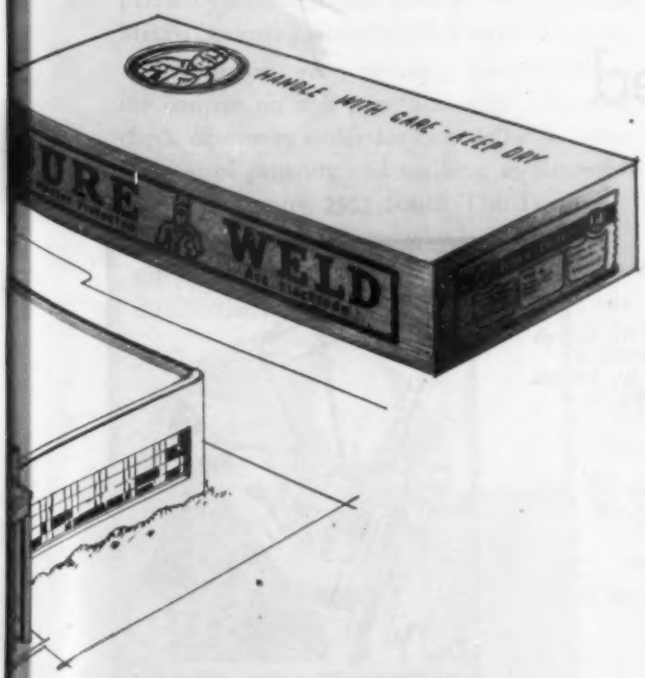

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Boyette, H. C. (C), 501 McKinley Ave., Pascagoula, Miss.
Davis, E. C. (C), 605 Roosevelt St., Pascagoula, Miss.
Kelly, J. E. (C), 328 McKinley St., Pascagoula, Miss.
Williams, O. G. (C), Box 661, Pascagoulas, Miss.

PEORIA

Cross, Stanley (C), 501 Willow St., Pekin, Ill.
Floyd, John (C), 200 Fourth Ave., Peoria, Ill.
Graebner, Albert C. (B), 203 N. Randolph St., Champaign, Ill.
Hartseil, Clarence (C), R. R. 3, Peoria, Ill.
Maroney, Allan (C), R. R. 2, Washington, Ill.

PHILADELPHIA

Bonowitz, Michael J. (B), 217 Catherine St., Philadelphia 47, Pa.
Davis, Harry E. (B), 6455 Upland St., W. Philadelphia 42, Pa.
Maul, Elmer W. (B), Superior Tube Co., Box 191, Norristown, Pa.
Yerger, Harvey, Jr. (C), King Fifth Wheel Co., 2915 N. Second St., Philadelphia, Pa.

PORTLAND, ORE.

Christensen, J. Loring (B), 320 S. E. 62nd Ave., Portland 16, Ore.
Hayden, John P. (B), 30 S. W. 2nd Ave., Portland 4, Ore.
Hoppe, William P. (B), 113 N. E. Fargo St., Portland, Oreg.
Peacor, Harold G. (B), 603 N. E. Halsey St., Portland 12, Ore.
Stith, Charles E. (B), American Bureau of Shipping, Rm. 722, Bd. of Trade Bldg., Portland, Ore.

ROCHESTER

Donato, P. (C), 137 Portland Ave., Rochester 5, N. Y.
Donavel, Frank (C), 12 Saratoga Ave., Rochester, N. Y.
Howe, William T. (C), 840 University Ave., Rochester, N. Y.
Jackson, Robert G. (C), 316 Broad St., Rochester, N. Y.
Johnson, O. Byron, (B), R. D. 1, Holcomb, N. Y.

ST. LOUIS

Guettermann, Joseph J. (C), 611 State St., Belleville, Ill.
Kight, Karl Y. (C), American Car & Foundry Co., Madison, Ill.

SAN FRANCISCO

McCormick, Robert (B), Pacific Metals Co., 3100—19th St., San Francisco, Calif.
Wiley, Richard C. (C), 865 Morro St., San Luis Obispo, Calif.

WASHINGTON, D. C.

Lambert, Comdr. Richard H., U.S.N. (C), Bureau of Ships, Code 692, Navy Dept., Washington 25, D. C.
Powell, John A. (B), 19 Sheridan Ave., West Springfield, Mass.
Vermes, Harold J. S. (B), P. O. Box 106, Forest Park Station, Springfield, Mass.
Vining, Richard H. (B), P. O. Box 634, Springfield, Mass.

WESTERN MASS.

Ballentine, Richard E. (C), Westinghouse Elec. Corp., Box 2025, Buffalo 5, N. Y.
Lytle, Arthur R. (C), 4625 Royal Ave., Niagara Falls, N. Y.
Plumb, Raymond W. (C), Buffalo Niagara Elec. Corp., 39 E. Genesee St., Buffalo 3, N. Y.

WICHITA

Dunham, J. H., Jr. (C), Philips & Easton Supply Co., 244 S. Wichita St., Wichita, Kan.
Irwin, John M. (C), 346 Lulu St., Wichita 7, Kan.
Jarman, D. E. (B), 1619 Fairmount Wichita 1, Kan.
Koerner, P. A. (B), 830 Coolidge, Wichita, Kan.
Rieke, Herbert A. (C), 139 N. Mathewson, Wichita, Kan.

YORK-CENTRAL PA.

Lewis, Eugene M. (B), Alloy Rods Co., York, Pa.
Scott, Porter D. (B), Alloy Rods Co., York, Pa.
Walsh, Edward R., (B), Alloy Rods Co., York, Pa.

NOT IN SECTIONS

Bjelland, Ingenior B. (B), Boks 71, Oslo, Norway.
Martin, Alan (B), 108-33rd Ave., N. Nashville 5, Tenn.
Reed, Howard B. (C), P. O. Box 174, Moorehead, Minn.
Stone, W. B. (C), American Metals Co., Alsina 1487, Buenos Aires, Argentina.
Strom, Sven G. (B), Drottningholmsvengen 256, Ulusundi, Sweden.
Zigler, Alex R. (C), 3434 Humboldt, Denver, Colo.

Members Reclassified

During Month of September

DETROIT

Davies, G. V. (from C to B), Canadian Bridge Co., Box 157, Walkerville, Ont., Canada.
Doerfler, P. F. (from C to B), Canadian Bridge Co., Box 157, Walkerville, Ont., Canada.
Pollock, F. J. (from C to B), Canadian Bridge Co., Box 157, Walkerville, Ont., Canada.
Ryder, F. J. (from C to B), Canadian Bridge Co., Box 157, Walkerville, Ont., Canada.

LEHIGH VALLEY

Bartholomew, Robert A. (from C to B), Lehigh Structural Steel Co., Allentown, Pa.
Frantz, Chas. F. (from C to B), Lehigh Structural Steel Co., Allentown, Pa.
Grebe, Karl A. (from C to B), Lehigh Structural Steel Co., Allentown, Pa.

LONG BEACH

Wynn, Arthur R. (from C to B), 261 Glendora Ave., Long Beach, Calif.

LOS ANGELES

Petralia, Jack J. (from C to B), 25 N. 3rd St., Alhambra, Calif.

MILWAUKEE

Friebel, G. J. (from C to B), 2352 N. 114th St., Milwaukee 13, Wis.

on Welding Aluminum

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ABSTRACTS OF CURRENT WELDING PATENTS

Prepared by V. L. Oldham

Printed copies of patents may be obtained for 25¢ from the Commissioner of Patents, Washington, D. C.

2,406,310—Beryllium Brazing—George J. Agule, inventor, Stamford, Conn., assignor to Machlett Laboratories Inc. (2 Claims)

This patent discloses a method of brazing a beryllium member to a metallic base to close one end of a hole therein, which method comprises placing a washer of brazing material between the beryllium member and the base which is on a support that closes the remaining end of the hole in the base. The beryllium member is pressed toward the base while air around the base is evacuated and the assembled parts are heated until the washer is melted and pushed out between the member and the plate.

2,406,365—Electrode Holder—Achilles C. Gough, inventor, Pocatello, Idaho. (9 Claims)

Gough's patented holder has an arm extending from it for positioning an electrode and the holder also has an audible signaling device on it. Electromagnetic means, actuated by the welding current, cause pivotal movement of the arm to strike a welding arc while the signaling device is actuated by means responsible to variations in the welding current.

2,406,474—Welding Arc Stabilizer—William W. Perrin, inventor, Albany, Calif., assignor to Ted Nelson, San Leandro, Calif. (2 Claims)

The patented stabilizer includes an electrode carrying chuck which has a current-carrying conductor connected in series with the chuck and coiled therearound adjacent the electrode.

2,406,694—Welding Machine—Raymond J. Kieffer, inventor, Tonawanda, N. Y., assignor to Columbus McKinnon Chain Corp. (5 Claims)

A welding machine including an intermittently driven chain feeding wheel, which is driven by a constant speed drive shaft, an auxiliary drive shaft, and means for rotating said auxiliary shaft above normal speed during the intermittent actuation of the chain feeding wheel is revealed in this patent. Such last-named means includes a two-part jack shaft one part of which is geared to the drive shaft and the other part of which is geared to the auxiliary shaft. Clutch means are provided to connect the parts of the jack shaft so that the auxiliary shaft can be driven at normal or above normal speed.

2,407,676—Welding Mechanism—Alexander L. Munson, inventor, Detroit, Mich. (1 Claim)

Munson's patented mechanism relates to a seam welding wheel which has a work engaging rim, an annular coolant passage adjacent the rim, and coolant circulating means connected to the passage. These coolant circulating means include a plurality of radially extending circumferentially spaced passages that connect to the annular passage with alternate radial passages being for opposite flow of fluid.

2,407,746—Oscillating Welding Rod—Jesse E. Johnson, inventor, Colbert, Wash. (8 Claims)

This patented rod is fusible, has a long slender shape and includes a number of reverse bends that have end loops. The intermediate portions, connecting the bends, extend at an angle to the rod's axis, and they form notches on the opposite sides of the rod. The notches have a greater depth than the distance between their opposite faces and the reverse bends are thicker than they are wide.

2,407,836—Electrode Holder for Use in Electric Welding—Frederick George Ketelbey and George Mason, inventors, Birmingham, England. (10 claims)

In this patent, a pair of electrode holding jaws each are provided with a mounting shank with the shanks being associated for relative movement. Toggle means are provided for controlling the positions of the shanks and these means are movable through an over-dead-center position so that the jaws will remain in gripping association without pressure from the operator.

Employment Service Bulletin

POSITION VACANT

V-199. Plant Welding Engineer. Product assembly by Resistance and Arc Welders—Standard, Automatic and Special. Materials are Aluminum Alloys and Steel—open-hearth, stainless and low-alloy high tensile. Location, Chicago, Ill. Salary—to be discussed.

V-200. Instructor wanted. Desire young man to take charge welding course in western university. Must hold degree from recognized engineering school. Desirable to handle occasional class in mechanisms or elementary machine design.

V-201. Sales engineers to live and work in the midwest. Good engineering background and experience in resistance welding essential. Sales experience desirable. In writing please include full details on education and experience and indicate salary desired.

SERVICES AVAILABLE

A-535. Twenty years of widely varied experience with welding. Master of Science degree, Mechanical Engineering. Six years' teaching and research experience. Have served as Section Chairman of A.W.S. Familiar with specifications, codes, radiography, etc. Age 37, married, white, and free to move. Can furnish excellent references.

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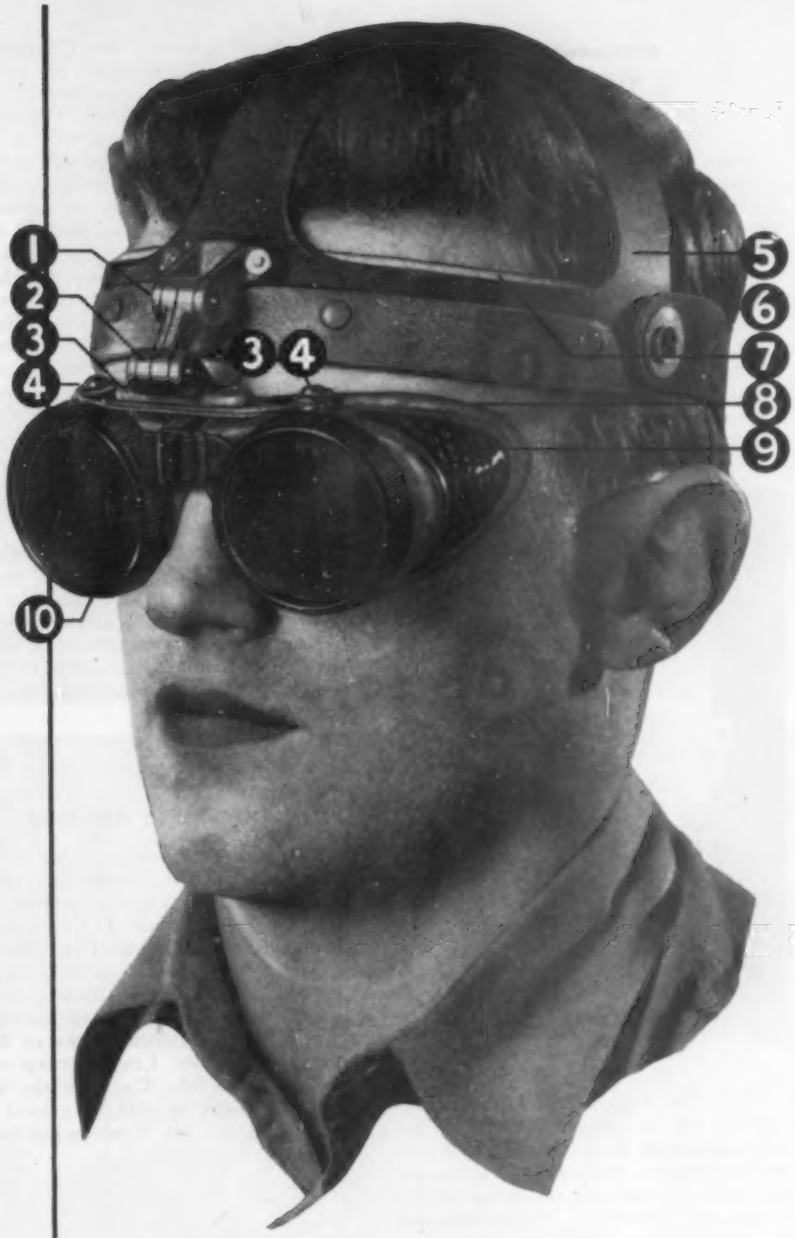

1 "OFF-GUARD" ADJUSTMENT
With one hand, welder can instantly throw goggle into "off-guard" position, where it is held securely by friction joint. Complete ventilation obtained each time goggle is raised.

2 FACIAL ADJUSTMENT
Positive friction joint enables goggle to be adjusted quickly to facial contour, and held firmly in place.

3 PD ADJUSTMENT
Nut and bolt assembly allows adjustment to proper pupillary distance. This adjustment is made only once for each individual.

4 SIDE ADJUSTMENT
Simple side adjustment enables wearer to fit eyecups flush against face to prevent any light leakage.

5 HEADGEAR
Comfortable headgear assembly of fibre construction fits snugly and distributes weight of goggle over entire head.

6 HEADGEAR ADJUSTMENT
Back headband is adjusted by knurled nut turning on right and left hand threaded stud. Headband slides within a fibre sleeve in back, permitting easy adjustment to varying head sizes, and preventing hair pulling.

7 SWEATBAND
Genuine leather sweatband affords additional comfort.

8 EYECUPS
Opaque eyecups are specially designed for wear directly over eyes or over personal prescription glasses.

9 SIDE SHIELDS
Indirect, ventilated side shields keep out stray light rays, sparks and metal splashes, yet provide ventilation to reduce fogging.

10 LENSES
Available with Noviweld lenses in shades 3, 4, 5, 6 or 8. May also be obtained with Noviweld-Didymium lenses in shades 3, 4, 5 or 6. Easily replaceable cover lenses protect filter lenses from pitting or scratching.

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OBITUARY

HENRY M. HOBART

Henry Metcalf Hobart, a retired consulting engineer of the General Electric Company, died in Schenectady on Oct. 11 after an illness of several weeks. His age was 77.

An expert on welding, Mr. Hobart developed mercury rectifiers and was an authority on arc welding, design of dynamo-electric machinery, insulation and standardization. A member of the national committee of the International Electro Technical Commission, he worked with the late Dr. Charles P. Steinmetz.

Henry M. Hobart

On Oct. 19, 1936, Mr. Hobart was presented with the Samuel Wylie Miller memorial medal of the AMERICAN WELDING SOCIETY, of which he was a founder and director. He was the editor of the *Dictionary of Electrical Engineering* and the author of many scientific works.

Born in Boston, the son of William and Martha Hobart, he was graduated from Massachusetts Institute of Technology in 1899 with a B.S. degree in electrical engineering. He became affiliated with the Thomson-Houston Electric Co., which was succeeded by General Electric in 1889 and later joined the British company of the same name.

In 1900 he joined the Union Electricitats Gesellschaft of Berlin, where he remained three years before going to London to take up an independent consulting practice.

He went to the Schenectady General Electric plant in 1911 as consulting engineer, a position he held until his retirement in February 1941.

Mr. Hobart was a former vice-president of the American Institute of Electrical Engineers and a Fellow of the American Association for the Advancement of Science. He also was a member of several British engineering organizations and had represented the AMERICAN WELDING SOCIETY on the engineering division of the National Research Council.

He leaves a widow, Mrs. Edith Walpole Hobart.

In 1918 there was organized a Welding Research Committee under the Welding Committee of the Emergency Fleet Corporation and Mr. Hobart was appointed its chairman. In September 1917 he went to London to study the applications of welding in the various yards of British shipbuilders, the Admiralty and private concerns. Mr. Hobart's report of this trip constituted the most comprehensive summary of the knowledge of the welding art available at that time. This marked the beginning of a research movement that has grown and spread to the four corners of the earth. There are very few of the earnest workers who were associated with these early endeavors who are still vitally interested in welding research.

The work of this Committee and its parent body, the Welding Committee of the Emergency Fleet Corporation, led to the organization of the AMERICAN WELDING SOCIETY and of the American Bureau of Welding, its research department.

From the American Bureau of Welding grew the Welding Research Council on which Mr. Hobart was active till his retirement in 1941.

THEODORE F. KIRCHNER

Theodore E. Kirchner, Sales Engineer for the Progressive Welder Co., Detroit, died of a heart attack on Aug. 10th, 1946. Mr. Kirchner was born in Cleveland and attended East Technical High School and Western Reserve College in Cleveland. He was a member of the Society of Automotive Engineers, the Engineering Society of Detroit and the AMERICAN WELDING SOCIETY. Mr. Kirchner came to the Progressive Welder Co. from the E. G. Budd Mfg. Co. in 1944, as a local sales representative. Mr. Kirchner had been ill for about two months.

MURRAY STANCLIFFE KICE, JR.

Murray S. Kice died on Sept. 25th at Harper Hospital in Detroit.

In Mr. Kice's passing the American Blower Corp. has lost one of its staunchest pillars and one of its most loyal supporters and capable engineers. The void which he leaves will be felt for many years to come.

Murray Stancliffe Kice was born in Louisville, Ky., on August 21, 1893. He attended Purdue University and was graduated in 1915 with the degree of B.S.M.E. After graduation he joined the staff of the American Blower Corp. His first assignment was as a mechanic in the large fan shop. He then served as erection superintendent for a period of one year after which he was transferred to the Engineering Department. In 1916 he was sent to the Pittsburgh office as sales engineer. Later, successively, Mr. Kice was made manager of the Columbus office, Cincinnati office and Indianapolis office. In 1927 he was called to the Home Office and made assistant to the Chief Engineer. In 1933 he was made Assistant Chief Engineer and in 1937 received the appointment of Chief Engineer.

During World War I Mr. Kice served in the armed forces and in July 1918 he received a commission as First Lieutenant in the 337th Field Artillery of the regular army. He served in France with his regiment and was discharged in April 1919.

He attained prominence in the industry as a writer of many published articles, and through serving on various committees. During his service with the company as Assistant Chief Engineer and as Chief Engineer, he contributed greatly to the company's progress in arc-welding technique, to the design of heavy duty and elevated temperature fans and to many simplified engineering procedures.

He was a member of the AMERICAN WELDING SOCIETY, the Engineering Society of Detroit, the Economic Club, American Society of Heating & Ventilating Engineers and the American Society of Mechanical Engineers. He was also a member of the Sons of the American Revolution, Society of Descendents of Founders of Hartford, Society of Indiana Pioneers, Phi Delta Theta fraternity, the Harlequin Club and the Oakland Hills Country Club.

FRED O. VOLZ

Fred O. Volz was born in Milwaukee on March 6, 1897. He entered the employ of the Lakeside Bridge and Steel Co. as an office boy in September 1913. He died September 6, 1946, at the age of 49 having served the company continuously for 33 years.

During the course of his employment he served successively in the drafting room, shop and engineering department holding the position of Assistant Sales Manager and Vice-President since 1930. He took a great deal of interest in welding and did much to improve the company's facilities in that direction since the installation of their first welding machine in 1923. He participated successfully in the James F. Lincoln Arc Welding Foundation competition of 1938 and had planned to participate in the 1946 program.

He is survived by his widow, Mrs. Winifred Volz of Milwaukee, and a son Fred J. of Coronado, Calif.

ORIN ANDREW WEISS

We regret to announce the death on August 12th of one of our good members, Orin Andrew Weiss, at the age of 43. Mr. Weiss was born in Minneapolis, Minn. He was a licensed engineer of the State of New York and active in consulting work. He was also licensed in New Jersey, Pennsylvania and Massachusetts. In addition to the AMERICAN WELDING SOCIETY, Mr. Weiss was a member of the A.S.M.E., S.A.E., the Technical Association of the Pulp and Paper Industry, Society of Military Engineers and the Army Ordnance Association. Mr. Weiss served in the U. S. Army in World War II.